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Air Pollution Technology, Inc., San Diego, CA

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PILOT DEMONSTRATION OF THE AIR CURTAIN SYSTEM FOR FUGITIVE PARTICLE CONTROL

By

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EPA Contract No. 68-02-3681

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Leakage	Fugitive Emissions	14G
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This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

ABSTRACT

Fugitive emissions constitute the major source of uncontrolled emissions for many industrial plants. There are presently no high performance, inexpensive control techniques available for many fugitive sources. Current technology is expensive, often marginally effective and typicaly consists of hooding at the source, or total building enclosure and evacuation. A simpler and less expensive method is to divert the emissions with an air curtain (and fans for some cases) into a control device located near the source. This greatly reduces processing of uncontaminated air. Under this U.S. EPA project, Air Pollution Technology, Inc. has demonstrated the technical and economic feasibility of using an air curtain transport system for controlling buoyant fugitive particle emissions from mold pouring operations at a Naval foundry in San Diego, California.

The pilot plant system used a horizontal air curtain to capture and convey the buoyant fugitive particle emissions to a particle collection filter unit. High Efficiency Particulate Air (HEPA) filters in the filter unit collected the particles with the aid of a set of suction fans. Results from the pilot plant tests indicated that the air curtain capture efficiency, the measure of the air curtains ability to capture and convey the fugitive emission plume, is between 63 and 105%, depending on the air curtain slot exit velocity, and subject to a ± 18% error limit. Results also indicated that the collection efficiency of the HEPA filters for the particle size range of the mold emissions is 99%. The overall capture and containment efficiency of the pilot plant when operating in the appropriate slot velocity range, can be expected to be between 90 and 99% when considered as a package.

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NOMENCLATURE

A = cross-sectional area of the plume, cm^2

A_s = cross-sectional area of slot, cm^2

b = half-width of air curtain at distance x from slot, cm

b_o = air curtain half-thickness, cm

d_a = air curtain density, g/cm^3

d_g = plume air density, g/cm^3

d_p = physical particle diameter, μm

dpa = aerodynamic particle diameter, μmA

d_{pg} = mass median diameter

g = acceleration of gravity = 981 cm/s^2

P = a relative indicator of air curtain power requirement

Q_{AC} = air curtain volumetric flow rate at filter unit inlet, cm^3/s

Q_{fu} = filter unit inlet volumetric flow rate, cm^3/s

Q_s = slot volumetric flow rate cm^3/s

Q_x = volumetric flow rate of air curtain at distance x from slot, cm^3/s.

S = a relative indicator of air curtain strength.

T_a = ambient air temperature, K

T_g = air curtain gas temperature, K

u_a = average velocity of air curtain at distance, x from slot, cm/s

u_c = centerline velocity of air curtain at distance x from slot, cm/s

u_g = plume rising velocity, cm/s

u_o = Average air curtain velocity where the hot plume and jet stream meet, cm/s

u_s = slot exit velocity, cm/s

u_w = crosswind velocity, cm/s

w = slot width, cm

x = distance from slot, cm

x_c = horizontal coordinate, cm

x_s = horizontal distance downstream of source, cm

z = vertical coordinate, cm

z = vertical rise of plume, cm

NOMENCLATURE Continued

Greek

σ_g = geometric std. deviation
μm = micrometer, $10^{-6}m$
μmA = micrometer aerodynamic, $\mu m\ (g/cm^3)^{1/2}$

SECTION 1

SUMMARY

INTRODUCTION

Fugitive emissions constitute the major source of uncontrolled emissions for many industrial plants. There are presently no high performance, inexpensive control techniques available for many fugitive sources. Current technology is expensive, often marginally effective and typically consists of hooding at the source, or total building enclosure and evacuation. A simpler and less expensive method is to divert the emissions with an air curtain (and fans for some cases) into a control device located near the source. This greatly reduces processing of uncontaminated air. Under this U.S. EPA project, Air Pollution Technology, Inc. has demonstrated the technical and economic feasibility of using an air curtain transport system for controlling buoyant fugitive particle emissions from mold pouring operations at a Naval foundry in San Diego, California. This project sought to demonstrate the technology of fugitive emission control. Our particular source was selected due to availability and the ability to demonstrate the technology.

OBJECTIVES

The principal objective of this project was to demonstrate the technical and economic feasibility of the use of a Spray, Charge and Trap (SCAT) system at an industrial site.

Objectives for this study were as follows:

1. Select a pilot plant demonstration site with a suitable industrial participant.
2. Conduct a series of operational design verification tests of the emission control system.
3. Demonstrate the pilot plant at the selected industrial site in order to compile an extensive performance characterization of the emission control system.
4. Produce a detailed evaluation of the emission control system.

PILOT PLANT DESCRIPTION

Pilot plant demonstration sites were investigated in order to determine an appropriate location with a significant source of fugitive emission pollution. After extensive investigation, a Naval maintenance foundry in San Diego, California was selected.

The SCAT scrubber system used air curtains and/or push jets to contain, divert and convey the fugitive emissions of an industrial process into a charged spray scrubber which would have used a low pressure drop entrainment separator to trap the spray drops and the collected particles for subsequent disposal. Extensive investigations into the characterization of the typical fugitive emissions to be controlled indicated, however, that the SCAT concept would not be applicable because of its complicated nature and its requirements for water supply. We determined that the appropriate particle collection device should rather be a filtration unit which would still operate in conjunction with air curtains and/or push jets to contain, divert and convey the fugitive emission of the industrial process.

The pilot plant unit designed and constructed consisted of an air curtain unit and a filter bank system.

The single slot air curtain unit was oriented in a horizontal manner and constructed with a support structure which enabled it to be completely adjustable in height and angle of orientation. The sizing and strength of the air curtain were determined by the design verification tests.

The filter bank unit consisted of an array of High Efficiency Particulate Air (HEPA) filters and suction fans to move the emission laden air through the unit. The filter bank was also designed to be adjustable in height.

The two complimentary units are arranged so that the air curtain sweeps air across the top of the fugitive emission source, traps and conveys the emissions, and delivers them to the filter unit for entrainment.

TEST METHODS

The overall effectiveness of the pilot plant unit is determined by two factors: the ability of the air curtain wedge to contain and convey the buoyant fugitive emission plume towards the collection device, and the ability of the particle collection device to collect the conveyed emission particles efficiently.

Air curtain capture efficiency was determined at the demonstration site with the use of a trace gas sulfur hexafluoride (SF_6). The SF_6 was injected directly into the buoyant mold plume after a metal pour. The air curtain air stream conveys both the mold emissions and the SF_6 to the filter unit. Careful sampling at the outlet of the filter unit was used to determine the concentrations of tracer gas in the outlet streams. The ratio of SF_6 outlet concentration measured to total SF_6 injection was used to determine the capture efficiency.

The filter collection efficiency was determined by the measurement of emission particle concentrations upstream and downstream of the HEPA filters used in the filter bank.

RESULTS

Results from the pilot plant tests indicate that the air curtain capture efficiency, the measure of the air curtains ability to capture and convey the fugitive emission plume, is between 63 and 105%, depending on the air curtain slot exit velocity. This number is subject to a ± 18% error limit. Results also indicated that the filter efficiency of the HEPA filters for the particle size range of the mold emissions is 99%.

CONCLUSIONS

The results of this study show that the use of an air curtain transport system in conjunction with a HEPA filter unit and suction fan arrangement provides an effective method for controlling buoyant emissions of foundry molds.

This study also indicates that, with properly designed and operated equipment, industrial fugitive emission sources of fine particles can be economically controlled while allowing full equipment and personnel access to the emission source area.

RECOMMENDATIONS

It is recommended that to expand upon the general utility of the information gathered in this project of air curtain control for fugitive particle emissions, certain further areas of application be investigated. In order to be used as an industrial system for general application, the effects of parameters such as crosswind control, scaling factors as a function of emission size, set-up parameters, and applicability of related system uses should be studied.

SECTION 2

INTRODUCTION

DESCRIPTION

Fugitive emissions are air pollution emissions which have not passed through a stack or duct. They are diffuse and typically come from many small sources rather than from a single large source. Fugitive particle emissions tend to be site-specific; with open operations, storage and disposal of materials and wastes, incompletely controlled point sources and poor housekeeping providing maximum potential for their release. One method for controlling buoyant fugitive emissions is to gather and convey them to conventional air pollution control devices. Typical systems of this type involve hooding at the local source of emissions, or total building enclosure and evacuation. These systems often require high capitol and energy costs, especially when there are many small, diffuse sources.

A simpler and less expensive method is to divert the emissions with air curtains (and fans for some cases) into a control device located near the source. An air curtain is a wedge-shaped flow field of air that is formed by blowing air through a slot. A major advantage of air curtains over hoods is that, for a given volumetric flow rate, an air curtain can cause air movement at a much greater distance than hoods (about 30 times greater). Another advantage is that air curtains allow free movement of equipment and personnel in the area to be controlled.

The principal objective of this project, sponsored by the U.S. EPA, was to demonstrate the technical and economic feasibility of the use of a Spray, Charge and Trap (SCAT) system at an industrial site. The SCAT scrubber system used air curtains and/or push jets to contain, divert and convey the fugitive emissions of an industrial process into a charged spray scrubber which would have used a low pressure drop entrainment separator to trap the spray drops and the collected particles for subsequent disposal. Extensive investigations into the characterization of the typical fugitive emissions to be controlled indicated, however, that the SCAT concept would not be applicable because of its complicated nature and requirements for water supply. We determined that the appropriate particle collection device should rather be a filtration unit which would still operate in conjunction with air curtains and/or push jets to contain, divert and convey the fugitive emission of the industrial process.

In this project, Air Pollution Technology, Inc. researched, designed, tested, modified, and constructed a pilot plant fugitive emission control system to be run at a demonstration site. The high velocity air curtain air streams entrain the fugitive particle emissions from foundry molds plus some additional air and carry them away from the source. At a convenient distance downstream, the particle laden air stream is pulled into a filter unit and the emission particles are removed. The cleaned gases are then exhausted into the atmosphere by the fans used to pull the air through the filter unit.

The overall effectiveness of the pilot plant unit is determined by two factors: the ability of the air curtain wedge to contain and convey the buoyant fugitive emission plume towards the collection device, and the ability of the particle collection device to collect the conveyed emission particles efficiently.

Scope of Work

This project demonstrates a fugitive particle emission control system on an industrial source which constitutes an important source of fine fugitive particulate.

TASK 1: SITE SELECTION

A pilot test agreement was negotiated with a suitable industrial participant. The terms of this agreement included the following:

A. The emission control system and duct work or heading hardware was provided as required by the plant configuration.

B. Field tests were conducted on-site at the participant's plant.

C. The test site was available for EPA personnel inspection.

On-site evaluation of the participant's process was conducted, as well as a review of the participant's data on process conditions and equipment requirements. Effects studied included process stream temperature, humidity, velocity, cross winds, and thermal plumes. Experiments were conducted to determine the design for the system as applied to the selected site. Using this data, a suitable control system design was selected, and hooding duct work or other adapting hardware designed. A test matrix was drawn up and presented to the EPA and to the industrial participant. Approval of the test matrix by the EPA Project Officer was obtained before initiation of Task 3.

TASK 2: PRE-DELIVERY DESIGN VERIFICATION TESTS

The emission control system was fabricated from the approved design of Task 1. A series of operational tests were conducted at in-house facilities to verify that the emission control system satisfied the Task 1 design objectives.

TASK 3: PILOT DEMONSTRATION OF FIELD TEST

A field test program was conducted from installation and start-up through performance characterization. The performance characterization was executed in accordance with the approved test matrix.

During performance characterization the following measurements were made:

A. All relevant process variables were measured, including process gas humidity, temperature and velocity.

B. Particle concentration at the inlet and exit of the emission control system was measured.

C. Particle size distribution in the process gas at the emission control system inlet and outlet, and fractional efficiency were determined. Particle size distribution was determined by cascade impactors in accordance with EPA Reports 600/2-76-023 and 600/2-76-118.

TASK 4: SUMMARY AND CONCLUSIONS

A detailed evaluation of the emission control system was conducted. The final evaluation considered how well the system performed in terms of air curtain capture efficiency and the fractional efficiency of the collection mechanisms. The advantages and limitations of the emission control system design for the selected application were evaluated. These included portability and unobtrusiveness, capitol costs, alternative system components and arrangements, particle collection mechanisms, safety considerations, and other factors.

SECTION 3
DEMONSTRATION SITE

Site Selection Criteria

Several criteria must have been met for the demonstration site to be suitable. It must have been an operation which occurred commonly and constitutes a significant source of pollution. Pollutant emissions which had health effects were especially important. In order to reduce travel costs as much as possible while attaining the program objectives, emphasis was placed on finding a site in Southern California. Source control by air curtain capture to particle collection equipment must have been either technologically or economically feasible if it was to be a suitable candidate. Another factor considered was whether source control required any of the special features of the SCAT, such as:

1. An open work area with a minimum of solid enclosures where free access around the fugitive particle source was required in the process.
2. Trapping of emissions to preclude re-dispersion or creation of other problems (water or air pollution).
3. Hot, buoyant plume capture.
4. Crosswind control.
5. Portability.
6. Simple and sturdy equipment.
7. Versatility to permit use on various sources.
8. Unobtrusive equipment.

Besides the special capabilities which give the SCAT an advantage over other control methods, there are some site requirements for the SCAT, as follows:

1. Space, upstream and downstream, was needed for the two sections of the SCAT.
2. The distance between the two sections of the SCAT was not to exceed about 6 m.
3. Tolerance for air jets blowing over the source perimeter.

For the sake of economical operation of the demonstration project, the following were desirable:

1. Host company willingness to cooperate with the project operation and to contribute a level of assistance or hardware.
2. Moderate source size to reduce equipment costs.
3. Site as near as possible to San Diego, to reduce the costs of travel.

SITE SEARCH

Using the above criteria, an extensive search was initiated to locate a suitable site at which the SCAT pilot plant arrangement could be installed and tested. To find these potential demonstration sites, the following agencies were contacted: San Diego County Air Pollution Control District, California Air Resources Board, and the Southern California Chapter of the American Foundrymen's Society.

Several foundries in San Diego, Orange, and Los Angeles Counties were considered and visited. Initially, it appeared that none of the San Diego foundries would be suitable in regards to the requirements of the project. After extensive investigations of those possibilities in the Los Angeles area, an appropriate candidate was located which had shown interest in providing a site for the SCAT demonstration project. The site with the greatest potential was a casting line being constructed in a new plant of an iron foundry. The SCAT would have been applied to either a pouring station or a cooling conveyer in the casting line. After many negotiations and delays, it became apparent that this foundry would not be on-line soon enough for this project. It was at this point that San Diego foundries were again contacted regarding their interest in a demonstration of the SCAT system. Personnel at one of these foundries suggested a foundry in the San Diego area which had not been previously recognized. This site was visited on December 29, 1982 and found to be a suitable site for demonstration of the SCAT system. It was also apparent that the foundry personnel showed a strong interest in participating in the program. Negotiations were commenced, and an agreement was reached in February, 1983 for use of these facilities for the demonstration. The SCAT concept was modified to use a filtration unit.

SELECTED SITE

Site Operations and Layout

The selected site was a Naval maintenance foundry in San Diego. This foundry pours steel, stainless steel, cast iron, aluminum, bronze, brass, and other metals. The production rate of the foundry is approximately 45 to 450 kg/day (100 to 1,000 lb/day), with an average of about one pour per day, 3 to 5 days a week, which provided adequate time and opportunity for testing the efficiency of the system.

The layout of the selected foundry is shown in Figure 1. It has separate areas for mold preparation, mold shakeout, metal melting, and mold pouring. Metal melting is carried out in six induction furnaces, with capacities ranging from 82 to 295 kg (180 to 650 lb) per melt.

After melting, the metal is transferred by crane, and poured into "air-set" sand molds which are usually arranged in a row. Typical lengths, widths, and heights of the molds range from 0.5 to 1.2 m (1.5 to 4 ft). Two combinations of mold materials are used. For most of the molds, a mixture of silica sand, silica flour, bentonites, and dextrin is used. For the larger molds, a mixture of silica sand, resin, and catalyst is used.

Pouring operations typically last only for 2 to 3 minutes. After pouring, the metal cools in the mold for up to 24 hours. After cooling, the molds are transferred to the shakeout area, where the cast parts are removed from the molds.

Source Characterization

As part of the site development, field evaluations of the fugitive emission source were conducted. Temperature and velocity profiles were measured to define the hot plume trajectory and flow rate, in order to aid in designing the air

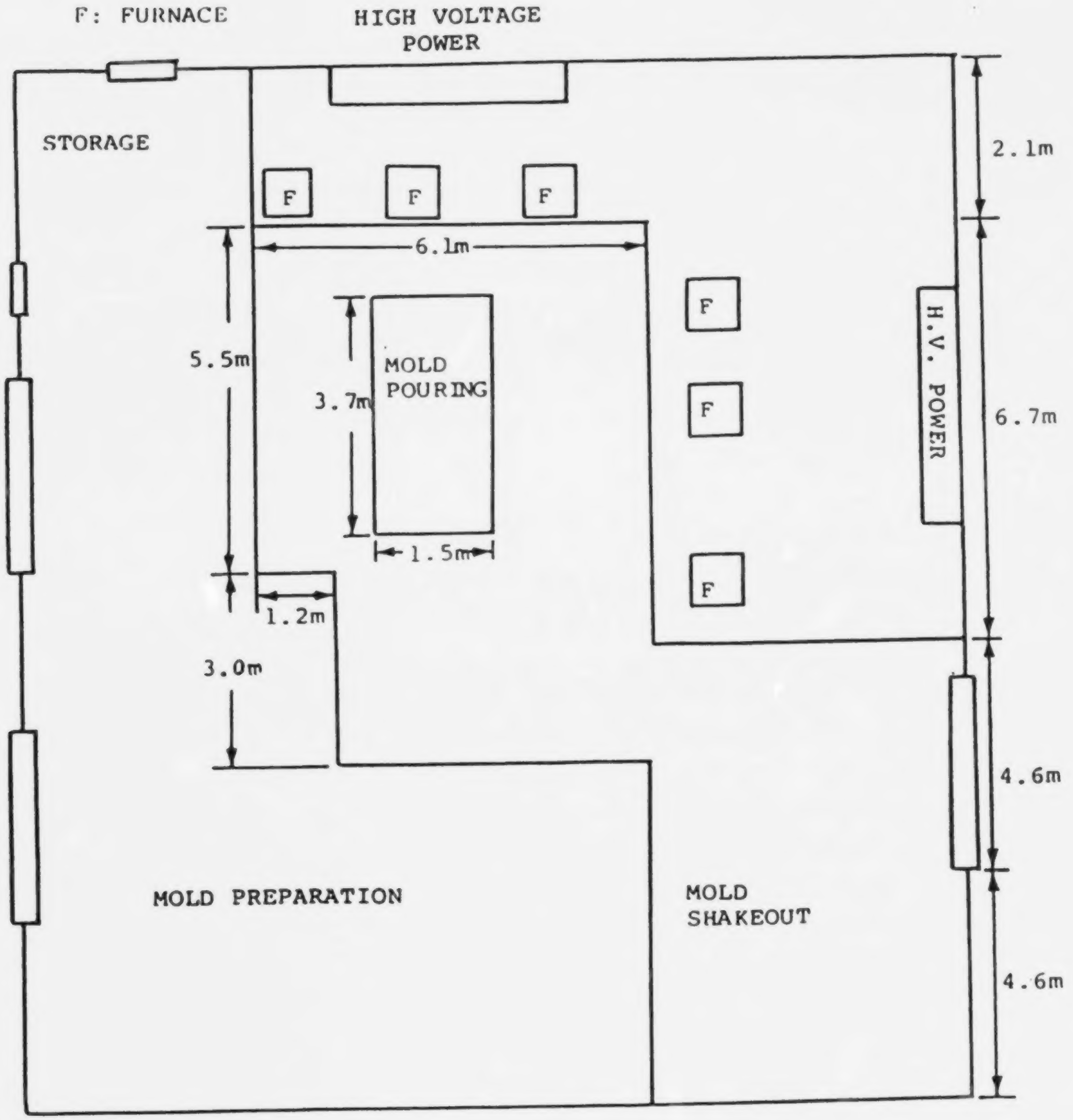

F: FURNACE
HIGH VOLTAGE POWER
STORAGE
F
F
F
6.1m
5.5m
3.7m
MOLD POURING
1.5m
1.2m
3.0m
F
F
F
H.V. POWER
2.1m
6.7m
4.6m
4.6m
MOLD PREPARATION
MOLD SHAKEOUT

Figure 1. Foundry layout.

curtain with which to contain the fugitive emissions. Particle size distribution and concentration were measured to establish collection efficiency requirements for the particle collection device.

Temperature and Velocity Profiles

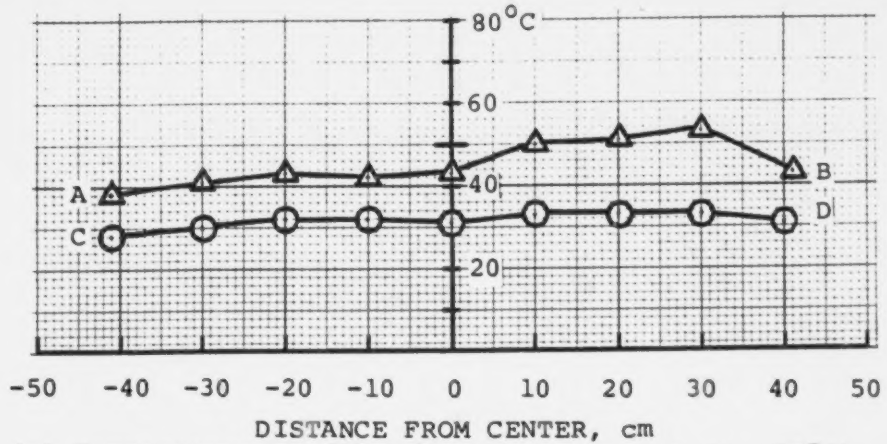
Information about the temperature and velocity profiles of the mold plumes are needed for the design of the air curtain which contains the mold emissions and conveys them to a particle collection device. Temperature profiles were measured using a thermocouple with digital readout, and velocity profiles were measured with a hot wire anemometer.

Profile measurements were made for three different foundry molds. For the first mold, at 61 cm above its surface, the average temperature and velocity were 30°C (86°F) and 8 cm/s (15 ft/min), respectively. For the other two molds profiled, results are shown in Figures 2 and 3. At 20 cm above the molds, the maximum temperature and velocity are 55°C and 40 cm/s, respectively.

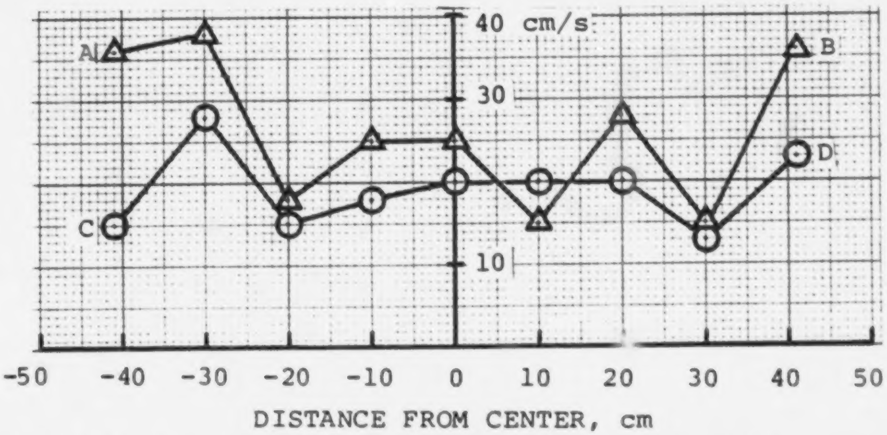
Particle Emission Characteristics

Particle size distribution and particle emission rate of foundry molds were measured to aid in the selection of a suitable particle control device and to specify its required collection efficiency.

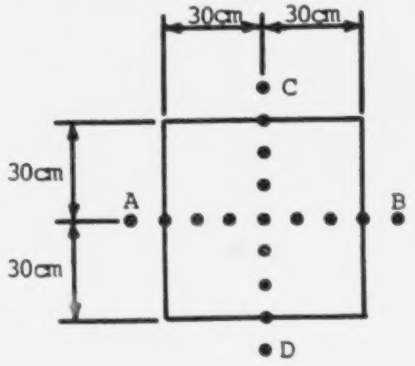
The particle sampling apparatus used is shown in Figure 4. The hood which captures the mold emissions, is large enough to cover the plume emitting areas of the top surface of the mold and is close enough to the mold to prevent crosswinds from deflecting plumes away from the hood. A representative sample is drawn through a sampling nozzle at the center of the duct 8 diameters downstream. Particles are fractionated with a University of Washington cascade impactor, which has its 6th and 7th stages removed and replaced with a spacer in order to permit an increased sample flow rate of 71 l/min (2.5 cfm). The sample train draws, monitors, and controls the sample flow and measures



(c) Temperature profile (ambient temperature: 22°C).

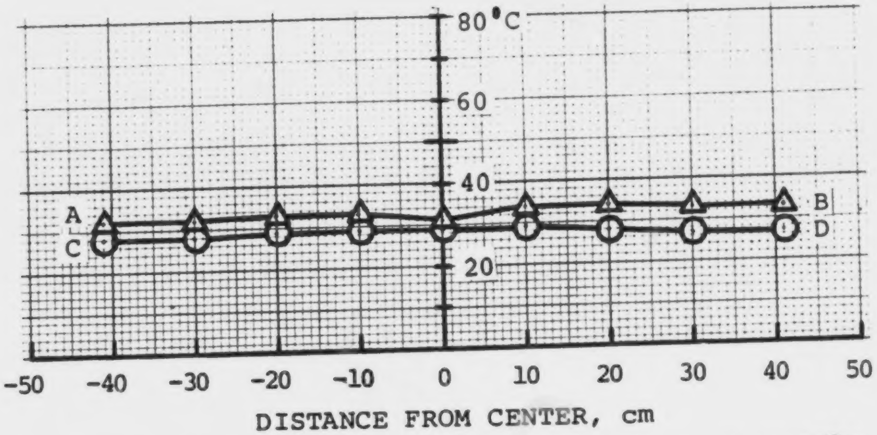


(b) Velocity profile (background: 8 to 20 cm/s).

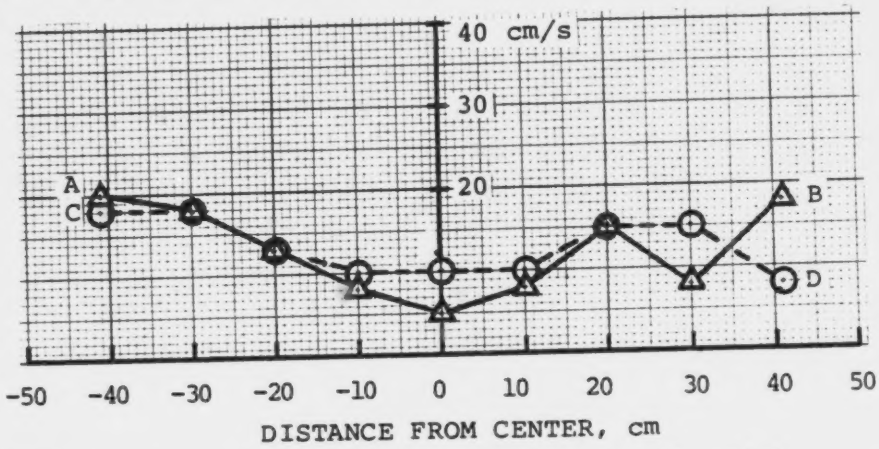

30cm
30cm
30cm
30cm
C
A
B
D

(a) Top view of mold.

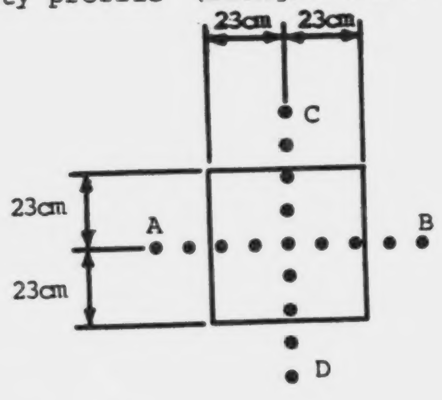
Figure 2. Temperature and velocity profiles at 20 cm above mold for first pour of May 5, 1983, at Naval foundry.



(c) Temperature profile (ambient temperature: 24 to 25°C).



(b) Velocity profile (background: 5 to 15 cm/s).



(a) Top view of mold.

Figure 3. Temperature and velocity profiles at 15 cm above mold for second pour of May 5, 1983, at Naval foundry.

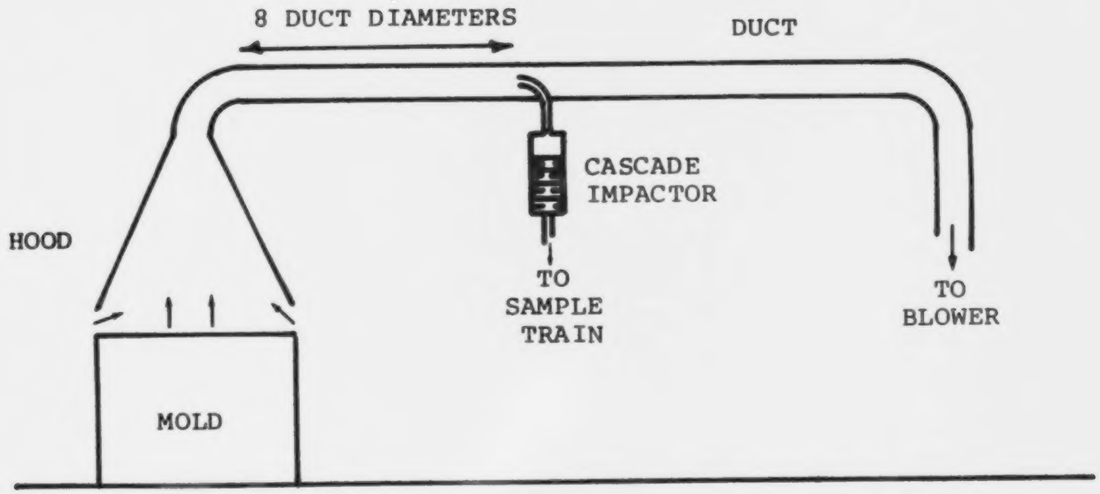

8 DUCT DIAMETERS
DUCT
CASCADE IMPACTOR
HOOD
TO SAMPLE TRAIN
TO BLOWER
MOLD

Figure 4. Mold plume sampling apparatus.

the volumetric flow rate, volume sampled, temperature, and pressure of the gas sample.

After molten metal has been poured into a mold, decreasing smoke plumes issue from the molds for 1 to 4 hours. Major emissions are metal fumes from the crucible during pouring and the smoke from combustion of the mold binders. The durations of the particle samples were between 3 and 30 minutes, depending on how soon the total filter of the cascade impactor became overloaded. The metal alloy and mold material was recorded for each particle sample (and temperature and velocity profile) so that statistical analyses of the emission rates and size distributions could be made for the metal and mold combinations.

Three samples of mold emissions were taken at the selected demonstration site. Analysis of these samples showed that a typical mold emits roughly 7 to 10 g/hr (0.015 to 0.022 lb/hr) of particles. Complete results are summarized in Table 1. Run Nos. 12-01 and 12-02 were taken from the same mold and pour, and indicate that the emission rate decreases with time. Run No. 12-03 was made after a pour of stainless steel. The emission rate appeared higher with stainless steel than with carbon steel. These samples also indicated that more than 70% of the mold emissions are smaller than 1 μm aerodynamic, and that the particles have a mass median diameter of 0.2 to 0.4 μm aerodynamic. Size distributions of the samples are illustrated in Figure 5.

TABLE 1. MOLD EMISSION RATE SUMMARY

Run No.	Metal Type	Metal Wt. (kg)	Sampling Time (minutes after pouring)	Emission Rates (Note 1)	
				(g/hr)	(g/hr-kg of metal)
12-01	carbon steel	130	8 to 19	8.58	0.066
12-02	carbon steel	130	64 to 67	6.83	0.053
12-03	stainless steel	50	16 to 46	9.50	0.19

Notes:

1. Emission rates include particles and volatile liquids.
2. Mold material for all samples is 98.0% silica sand, 1.2% deep set hardener, and 0.8% catalyst.

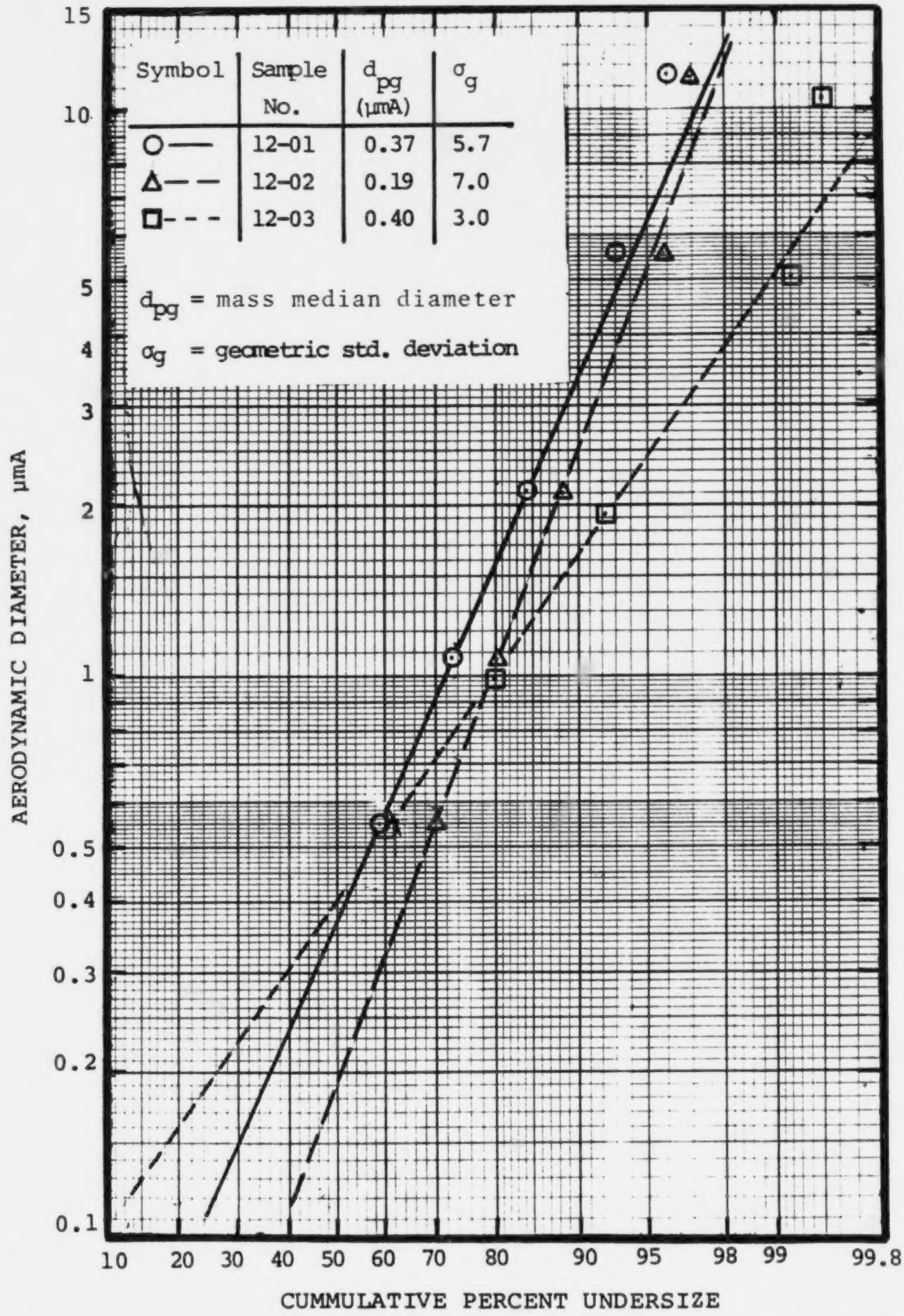


Figure 5. Particle and volatile droplet size distributions of foundry mold emissions.

SECTION 4

PILOT PLANT DESCRIPTION

ARRANGEMENT

Generalized Pilot Plant Arrangement

The pilot plant is composed of two portions; an emission capture system and a particle collection system. The emission capture system uses air curtains to deflect area crosswinds, to contain the buoyant emission plumes, and to convey emissions to a particle collection device. A generalized arrangement for the air curtain control system is shown in Figure 6. The horizontally oriented air curtain unit contains the buoyant plume from the emission source. The two vertical air curtains deflect area crosswinds. The fan is used to move the emissions to the particle collection device

Specific Pilot Plant Arrangement

The specific pilot plant arrangement used at the selected demonstration site is shown in Figure 7. Since the location of the demonstration pilot plant is indoors, the vertical air curtains are not required to deflect crosswinds. Also, since the volume of the emission plume is relatively small, a push fan was not required. A single, horizontally oriented air curtain was used to capture and convey the mold plume to the particle collection device.

AIR CURTAIN UNIT

Design of the air curtain was based on the following equations of Yung et al. (1981).

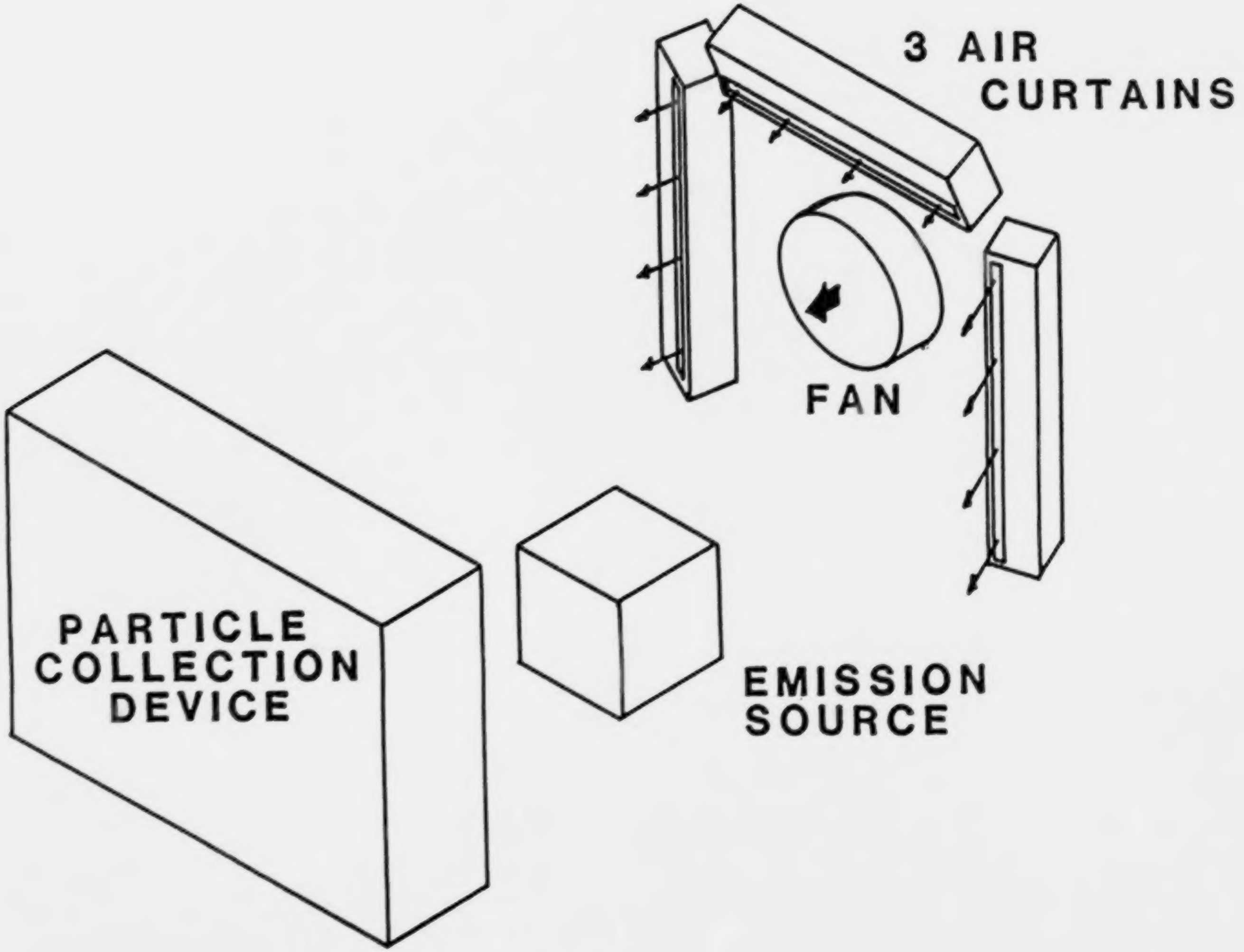

3 AIR
CURTAINS
FAN
PARTICLE
COLLECTION
DEVICE
EMISSION
SOURCE

Figure 6. Generalized air curtain control system.

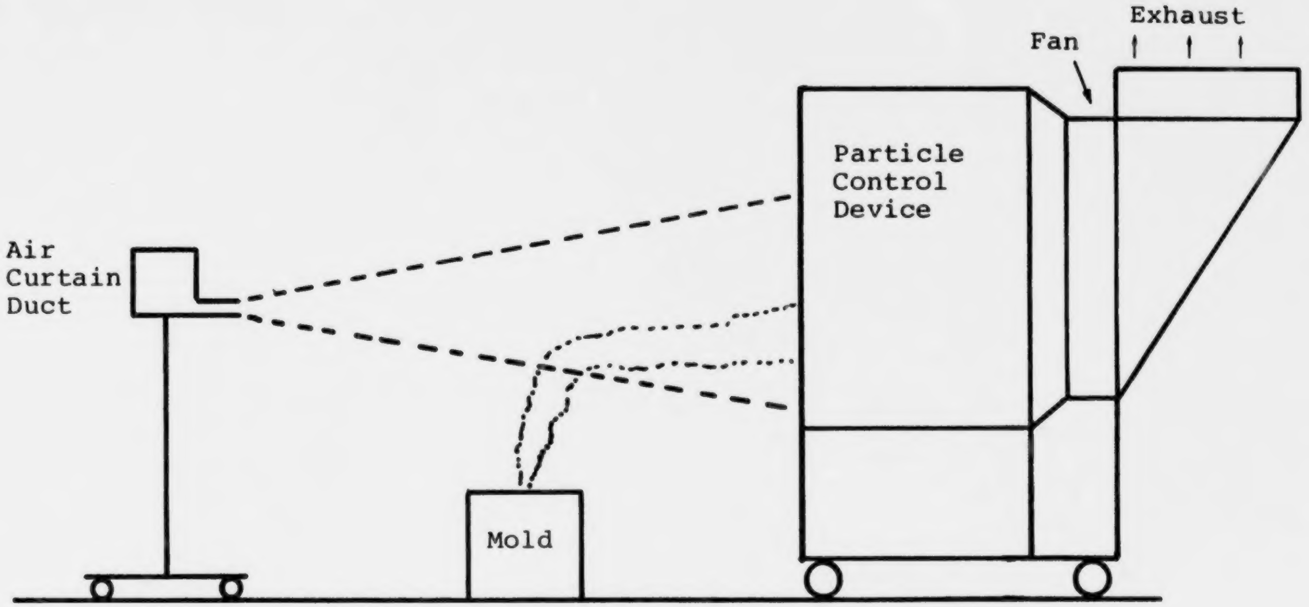

Air
Curtain
Duct
Mold
Particle
Control
Device
Fan
Exhaust

Figure 7. Pilot plant arrangement

Air Curtain Flow Field Equations

Equations which describe the air curtain flow field are:

$$u_c = 2.45\ u_s\ (w/x)^{1/2} \qquad (1)$$

$$u_a = u_c\ /\ 1.86 \qquad (2)$$

$$b = 0.22\ x \qquad (3)$$

$$Q_s = u_s\ A_s \qquad (4)$$

$$Q_x = 0.66\ Q_s\ (x/w)^{1/2} \qquad (5)$$

where: u_c = centerline velocity of air curtain at distance x from slot, cm/s
u_s = slot exit velocity, cm/s
w = slot width, cm
x = distance from slot, cm
u_a = average velocity of air curtain at distance x from slot, cm/s
b = half-width of air curtain at distance x from slot, cm
Q_s = slot volumetric flow rate, cm^3/s
A_s = cross-sectional area of slot, cm^2
Q_x = volumetric flow rate of air curtain at distance x from slot, cm^3/s.

Equation (2) indicates that the average velocity at any cross-section of an air curtain is independent of the slot width and slot exit velocity. Equation (3) shows that the expansion angle of an air curtain is independent of the slot width and slot exit velocities. Thus, from equation (1), it can be concluded that:

$$\begin{array}{c}\text{Air}\\\text{Curtain}\\\text{Strength}\end{array} \propto \begin{array}{c}\text{Air}\\\text{Curtain}\\\text{Velocities}\end{array} \propto u_s\ w^{1/2} = S \qquad (6)$$

where: S = a relative indicator of air curtain strength.

Plume Trajectory Equations

The following equations for a buoyant plume with negligible exit momentum flux were used to determine the plume elevation within the air curtain.

$$z = \frac{1.6\, F^{1/3}\, x_s^{2/3}}{u_w} \tag{7}$$

and $$F = \frac{g\, A\, u_g\, (d_a - d_g)}{d_a} \tag{8}$$

where:
z = vertical rise of plume, cm
x_s = horizontal distance downstream of source, cm
u_w = crosswind velocity, cm/s
g = acceleration of gravity = 981 cm/s^2
A = cross-sectional area of the plume, cm^2
u_g = plume rising velocity, cm/s
d_a = air curtain density, g/cm^3
d_g = plume air density, g/cm^3

Air Curtain Trajectory Equation

The equation for air curtain centerline elevation is:

$$\frac{z}{b_o} = \frac{0.1\, g\, b_o\, (T_g - T_a)}{u_o^2\, T_a} (x_c / b_o)^{2.5} \tag{9}$$

where:
z = vertical coordinate, cm
g = acceleration of gravity = 981 cm/s^2
b_o = air curtain half-thickness, cm
T_g = air curtain gas temperature, K
T_a = ambient air temperature, K
u_o = average air curtain velocity where the hot plume and jet stream meet, cm/s
x_c = horizontal coordinate, cm

Air Curtain Power Requirements

To investigate the power requirements of an air curtain, the energy equations for air curtain manifolds of Yung et al. (1981) were used. Assuming that gas velocities within the manifold are negligible in comparison to the slot exit velocities, it can be concluded that:

$$\text{Manifold static Pressure} = P_m \propto u_s^2 \qquad (10)$$

and

$$\begin{aligned}\text{Air Curtain Blower Power Requirement} &\propto Q_s\ P_m\\ &\propto (u_s\ w)\ (u_s^2)\\ &\propto w\ u_s^3 = P \qquad (11)\end{aligned}$$

where: u_s = slot exit velocity, cm/s

Q_s = slot volumetric flow rate, cm³/s

P = a relative indicator of air curtain power requirement

The relationship between "Air Curtain Strength" and "Air Curtain Power Requirement" is illustrated in Figure 8 where S and P are plotted as functions of slot width and slot exit velocity. Figure 8 shows that for a given level of air curtain strength, the power requirement decreases as the width increases.

AIR CURTAIN DESIGN

Design Parameters

Air curtain design is based on the emission source parameters shown in Table 2. Design values for the first four parameters are larger than the measured values to include extra capacity in the design. Air curtain design procedures involved using trajectory theory to determine "Air Curtain Strength" and then selecting the largest practical slot width.

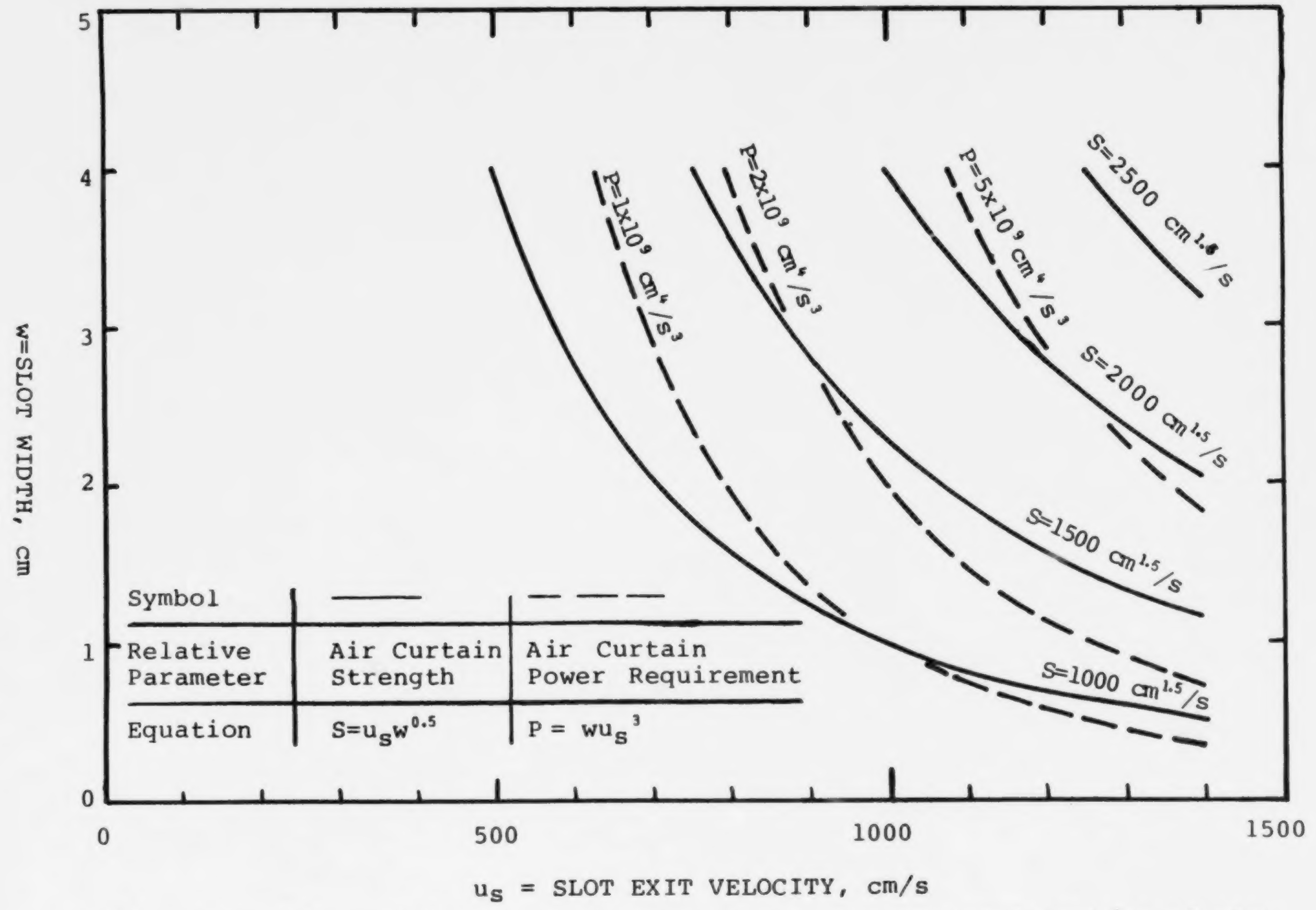


Figure 8. Air curtain power requirement and strength as functions of slot width and slot exit velocity.

TABLE 2. AIR CURTAIN DESIGN PARAMETERS

PARAMETER	MEASURED VALUE	DESIGN VALUE
Temperature at 30 cm (12 in.) above mold	32°C (90°F)	93°C (200°F)
Plume rise velocity at 30 cm above mold	3 to 56 cm/s (5 to 110 ft/min)	84 cm/s (165 ft/min)
Cross-sectional area of plume	undefined	2800 cm^2 (3 ft^2)
Largest mold size	76cm X 76cm X 81cm high (30" X 30" X 32" high)	107cm each side (42" each side)
Distance from air curtain slot to particle collection device	305 to 396 cm (10 to 13 ft)	305 to 396 cm (10 to 13 ft)
Distance from air curtain slot to mold plume centerline	61 to 335 cm (2 to 11 ft)	61 to 335 cm (2 to 11 ft)
Maximum height of particle collection device	270 cm	270 cm

Trajectory Calculations

The first step in air curtain design procedure is to compute theoretical plume and air curtain trajectories for combinations of air curtain slot widths and slot velocities using the trajectory equations. Results are shown in Tables 3 through 9. Figure 9 shows the trajectories of the plume and air curtain centerlines for a fixed gas slot exit velocity and several slot widths. Plume rise and air curtain rise decrease with increasing slot width. For a fixed air curtain volumetric flow rate, the effects of varying the slot width and slot exit velocity are shown in Figure 10. Plume rise and air curtain rise decrease with increasing slot exit velocity.

"Air Curtain Strength" (S) from equation (6) was computed for the combinations of air curtain slot widths and slot velocities that yielded trajectories which met the maximum height requirement of the particle control device. These values are presented in Figure 11. These values indicate that the order of magnitude of air curtain strength (S) required for the pilot plant's air curtain was 2,000 $cm^{1.5}/s$.

Minimizing Power Requirements

Commercial air curtain units were investigated using "Air Curtain Strength" (S) from above. A unit that exceeded this (S) value was selected. It is apparent from Figure 11 that for a given level of air curtain strength, the power requirement decreases as the slot width increases. This indicates that in order to minimize power requirements the air curtain should have as large a slot width as possible for the given (S) range. A search of commercially available units indicated only one size of slot width was available for the desired (S) range. Thus, this power relationship was not tested.

The air curtain selected had the following values and was based on the above design procedures, the mold dimensions and the mass produced air curtains available:

TABLE 3.

CACULATION TABLE FOR AN AIR CURTAIN AS A LID FOR A HOT MOLD

Title: try 6

Date: 18May83

User: Mike

Atm. Pressure
(in. Hg.)= 30

```
Elevation
    |
    |    ___
    |  |   | |<------     183cm>|
    |  |   |_                   |
    |  |_____ -------           |
    |            /\             |
    |            ||           -----
    |              152 cm    |     |
    |            ||          |mold |
    |            \/          |     |
777777777777777777777777777777777777
```

AIR CURTAIN

Input Parameters		Calculated Parameters above center of mold	
Slot Width (cm)=	1.27	C.L. Velocity (cm/s)=	207.37
Exit Velocity(cm/s)=	1016	Avg. Velocity (cm/s)=	111.49
Elev. of Slot (cm)=	152	Half Width (cm)=	40.26
Curtain Temp. (C)=	20	Elev. of Bottom (cm)=	111.74
Dist. to Mold (cm)=	183		

PLUME OF MOLTEN METAL MOLD

Input Parameters		Calculated Parameters	
Temp. @ Curtain (C)=	93	Density (g/cm3)=	.00097
Rising Vel. (cm/s)=	84	A.C. Dens. (g/cm3)=	.00121
X-sec. Area (cm2)=	2800	Buoy. Flux (cm4/s3)=	4.60e7

PLUME MIXED WITH AIR CURTAIN

Input Parameters		Trajectory Equations	
Temperature (C)=	38	Plume El.(cm)=	5.1121*x0.667
Amb. Temp. (C)=	20	A. C. El.(cm)=	.00008*x2.5

x, Distance downstream of mold (cm)	Plume Elevation (cm)	Air Curtain Centerline Elevation (cm)
30	161.15	152.38
91	215.32	158.03
152	257.58	173.76
213	294.39	202.57
274	327.80	246.91

TABLE 4.

CACULATION TABLE FOR AN AIR CURTAIN AS A LID FOR A HOT MOLD

```
Title: try 7                        Elevation
                                        |
Date:  18May83                          |   ___
                                        |  |   | |<------     183cm>|
User:  Mike                             |  |   |_                   |
                                        |  |_____  -------          |
Atm. Pressure                           |            /\             |
   (in. Hg.)=        30                 |            ||           -----
                                        |            152 cm      |     |
                                        |            ||          |mold |
                                        |            \/          |     |
                                     77777777777777777777777777777777777


AIR CURTAIN
          Input Parameters                     Calculated Parameters
Slot Width (cm)=            2.54                above center of mold
Exit Velocity(cm/s)=        1016        C.L. Velocity (cm/s)= 293.26
Elev. of Slot (cm)=          152        Avg. Velocity (cm/s)= 157.67
Curtain Temp. (C)=            20        Half Width (cm)=       40.26
Dist. to Mold (cm)=          183        Elev. of Bottom (cm)= 111.74


PLUME OF MOLTEN METAL MOLD
          Input Parameters                  Calculated Parameters
Temp. @ Curtain (C)=          93        Density (g/cm3)=        .00097
Rising Vel. (cm/s)=           84        A.C. Dens. (g/cm3)=     .00121
X-sec. Area (cm2)=          2800        Buoy. Flux (cm4/s3)=   4.60e7


PLUME MIXED WITH AIR CURTAIN
          Input Parameters                  Trajectory Equations
Temperature (C)=              38        Plume El.(cm)= 3.6148*x0.667
Amb. Temp. (C)=               20        A. C. El.(cm)= .00004*x2.5


          x,                    Plume               Air Curtain
       Distance               Elevation             Centerline
       downstream               (cm)                Elevation
       of mold                                         (cm)
          (cm)

          30                   146.68                152.19
          91                   184.98                155.02
         152                   214.87                162.88
         213                   240.89                177.29
         274                   264.52                199.46
```

TABLE 5.

CACULATION TABLE FOR AN AIR CURTAIN AS A LID FOR A HOT MOLD

```
Title: try 8                Elevation
                                |
Date:  18May83                  |   ___
                                |  |   | |<------    183cm>|
User:  Mike                     |  |   |_                  |
                                |  |_____  -------         |
Atm. Pressure                   |            /\            |
   (in. Hg.)=      30           |            ||          -----
                                |             152 cm    |     |
                                |            ||         |mold |
                                |            \/         |     |
                            777777777777777777777777777777777777


AIR CURTAIN
       Input Parameters                  Calculated Parameters
Slot Width (cm)=          5.08           above center of mold
Exit Velocity(cm/s)=      1016       C.L. Velocity (cm/s)= 414.73
Elev. of Slot (cm)=        152       Avg. Velocity (cm/s)= 222.97
Curtain Temp. (C)=          20       Half Width (cm)=        40.26
Dist. to Mold (cm)=        183       Elev. of Bottom (cm)= 111.74

PLUME OF MOLTEN METAL MOLD
       Input Parameters                  Calculated Parameters
Temp. @ Curtain (C)=        93       Density (g/cm3)=       .00097
Rising Vel. (cm/s)=         84       A.C. Dens. (g/cm3)=    .00121
X-sec. Area (cm2)=        2800       Buoy. Flux (cm4/s3)=   4.60e7

PLUME MIXED WITH AIR CURTAIN
       Input Parameters                  Trajectory Equations
Temperature (C)=            38       Plume El.(cm)= 2.5560*x0.667
Amb. Temp. (C)=             20       A. C. El.(cm)= .00002*x2.5


          x,                 Plume                 Air Curtain
       Distance            Elevation               Centerline
       downstream            (cm)                  Elevation
       of mold                                       (cm)
         (cm)

            30              136.45                  152.09
            91              163.53                  153.51
           152              184.66                  157.44
           213              203.07                  164.64
           274              219.77                  175.73
```

TABLE 6.

CACULATION TABLE FOR AN AIR CURTAIN AS A LID FOR A HOT MOLD

Title: try 9

Date: 18May83

User: Mike

Atm. Pressure
(in. Hg.)= 30

```
Elevation
 |
 |    ___
 |   |   | |<------     183cm>|
 |   |   |_                    |
 |   |_____ -------            |
 |            /\               |
 |            ||              -----
 |            152 cm         |     |
 |            ||             |mold |
 |            \/             |     |
7777777777777777777777777777777777777
```

AIR CURTAIN

Input Parameters
Slot Width (cm)= 7.62
Exit Velocity(cm/s)= 1016
Elev. of Slot (cm)= 152
Curtain Temp. (C)= 20
Dist. to Mold (cm)= 183

Calculated Parameters
above center of mold
C.L. Velocity (cm/s)= 507.94
Avg. Velocity (cm/s)= 273.09
Half Width (cm)= 40.26
Elev. of Bottom (cm)= 111.74

PLUME OF MOLTEN METAL MOLD

Input Parameters
Temp. @ Curtain (C)= 93
Rising Vel. (cm/s)= 84
X-sec. Area (cm2)= 2800

Calculated Parameters
Density (g/cm3)= .00097
A.C. Dens. (g/cm3)= .00121
Buoy. Flux (cm4/s3)= 4.60e7

PLUME MIXED WITH AIR CURTAIN

Input Parameters
Temperature (C)= 38
Amb. Temp. (C)= 20

Trajectory Equations
Plume El.(cm)= 2.0870*x0.667
A. C. El.(cm)= .00001*x2.5

x, Distance downstream of mold (cm)	Plume Elevation (cm)	Air Curtain Centerline Elevation (cm)
30	131.91	152.06
91	154.03	153.01
152	171.28	155.63
213	186.31	160.43
274	199.95	167.82

TABLE 7.

CACULATION TABLE FOR AN AIR CURTAIN AS A LID FOR A HOT MOLD

```
Title: try 10               Elevation
                                 |
Date:  18May83                   |  ___
                                 | |   | |<------    183cm>|
User:  Mike                      | |   |_                  |
                                 | |_____ -------          |
Atm. Pressure                    |           /\            |
   (in. Hg.)=      30            |           ||           -----
                                 |            152 cm     |     |
                                 |           ||          |mold |
                                 |           \/          |     |
                            777777777777777777777777777777777777


AIR CURTAIN
       Input Parameters                     Calculated Parameters
Slot Width (cm)=         10.16              above center of mold
Exit Velocity(cm/s)=       254        C.L. Velocity (cm/s)= 146.63
Elev. of Slot (cm)=        152        Avg. Velocity (cm/s)= 78.833
Curtain Temp. (C)=          20        Half Width (cm)=       40.26
Dist. to Mold (cm)=        183        Elev. of Bottom (cm)= 111.74

PLUME OF MOLTEN METAL MOLD
       Input Parameters                     Calculated Parameters
Temp. @ Curtain (C)=        93        Density (g/cm3)=      .00097
Rising Vel. (cm/s)=         84        A.C. Dens. (g/cm3)=   .00121
X-sec. Area (cm2)=        2800        Buoy. Flux (cm4/s3)=  4.60e7

PLUME MIXED WITH AIR CURTAIN
       Input Parameters                     Trajectory Equations
Temperature (C)=            38        Plume El.(cm)= 7.2295*x0.667
Amb. Temp. (C)=             20        A. C. El.(cm)= .00015*x2.5


          x,                Plume                 Air Curtain
       Distance           Elevation               Centerline
       downstream           (cm)                  Elevation
       of mold                                       (cm)
         (cm)

           30               181.62                  152.75
           91               258.22                  164.07
          152               317.99                  195.51
          213               370.05                  253.14
          274               417.30                  341.83
```

TABLE 8.

CACULATION TABLE FOR AN AIR CURTAIN AS A LID FOR A HOT MOLD

Title: try 11

Date: 18May83

User: Mike

Atm. Pressure (in. Hg.)= 30

```
Elevation
    |
    |   ___
    |  |   | |<------    183cm>|
    |  |   |_                  |
    |  |_____ -------          |
    |            /\            |
    |            ||             -----
    |             152 cm      |     |
    |            ||           |mold |
    |            \/           |     |
77777777777777777777777777777777777
```

AIR CURTAIN

Input Parameters		Calculated Parameters above center of mold	
Slot Width (cm)=	5.08	C.L. Velocity (cm/s)=	207.37
Exit Velocity(cm/s)=	508	Avg. Velocity (cm/s)=	111.49
Elev. of Slot (cm)=	152	Half Width (cm)=	40.26
Curtain Temp. (C)=	20	Elev. of Bottom (cm)=	111.74
Dist. to Mold (cm)=	183		

PLUME OF MOLTEN METAL MOLD

Input Parameters		Calculated Parameters	
Temp. @ Curtain (C)=	93	Density (g/cm3)=	.00097
Rising Vel. (cm/s)=	84	A.C. Dens. (g/cm3)=	.00121
X-sec. Area (cm2)=	2800	Buoy. Flux (cm4/s3)=	4.60e7

PLUME MIXED WITH AIR CURTAIN

Input Parameters		Trajectory Equations	
Temperature (C)=	38	Plume El.(cm)=	5.1121*x0.667
Amb. Temp. (C)=	20	A. C. El.(cm)=	.00008*x2.5

x, Distance downstream of mold (cm)	Plume Elevation (cm)	Air Curtain Centerline Elevation (cm)
30	161.15	152.38
91	215.32	158.03
152	257.58	173.76
213	294.39	202.57
274	327.80	246.91

TABLE 9.

CACULATION TABLE FOR AN AIR CURTAIN AS A LID FOR A HOT MOLD

Title: try 12

Date: 18May83

User: Mike

Atm. Pressure (in. Hg.)= 30

```
Elevation
    |
    |     ___
    |   |   | |<------     183cm>|
    |   |   |_                   |
    |   |_____  -------          |
    |             /\             |
    |             ||           -----
    |             152 cm      |     |
    |             ||          |mold |
    |             \/          |     |
7777777777777777777777777777777777777
```

AIR CURTAIN

Input Parameters
Slot Width (cm)= 1.69
Exit Velocity(cm/s)= 1524
Elev. of Slot (cm)= 152
Curtain Temp. (C)= 20
Dist. to Mold (cm)= 183

Calculated Parameters above center of mold
C.L. Velocity (cm/s)= 358.81
Avg. Velocity (cm/s)= 192.91
Half Width (cm)= 40.26
Elev. of Bottom (cm)= 111.74

PLUME OF MOLTEN METAL MOLD

Input Parameters
Temp. @ Curtain (C)= 93
Rising Vel. (cm/s)= 84
X-sec. Area (cm2)= 2800

Calculated Parameters
Density (g/cm3)= .00097
A.C. Dens. (g/cm3)= .00121
Buoy. Flux (cm4/s3)= 4.60e7

PLUME MIXED WITH AIR CURTAIN

Input Parameters
Temperature (C)= 38
Amb. Temp. (C)= 20

Trajectory Equations
Plume El.(cm)= 2.9544*x0.667
A. C. El.(cm)= .00003*x2.5

x, Distance downstream of mold (cm)	Plume Elevation (cm)	Air Curtain Centerline Elevation (cm)
30	140.30	152.13
91	171.60	154.02
152	196.03	159.27
213	217.30	168.89
274	236.61	183.70

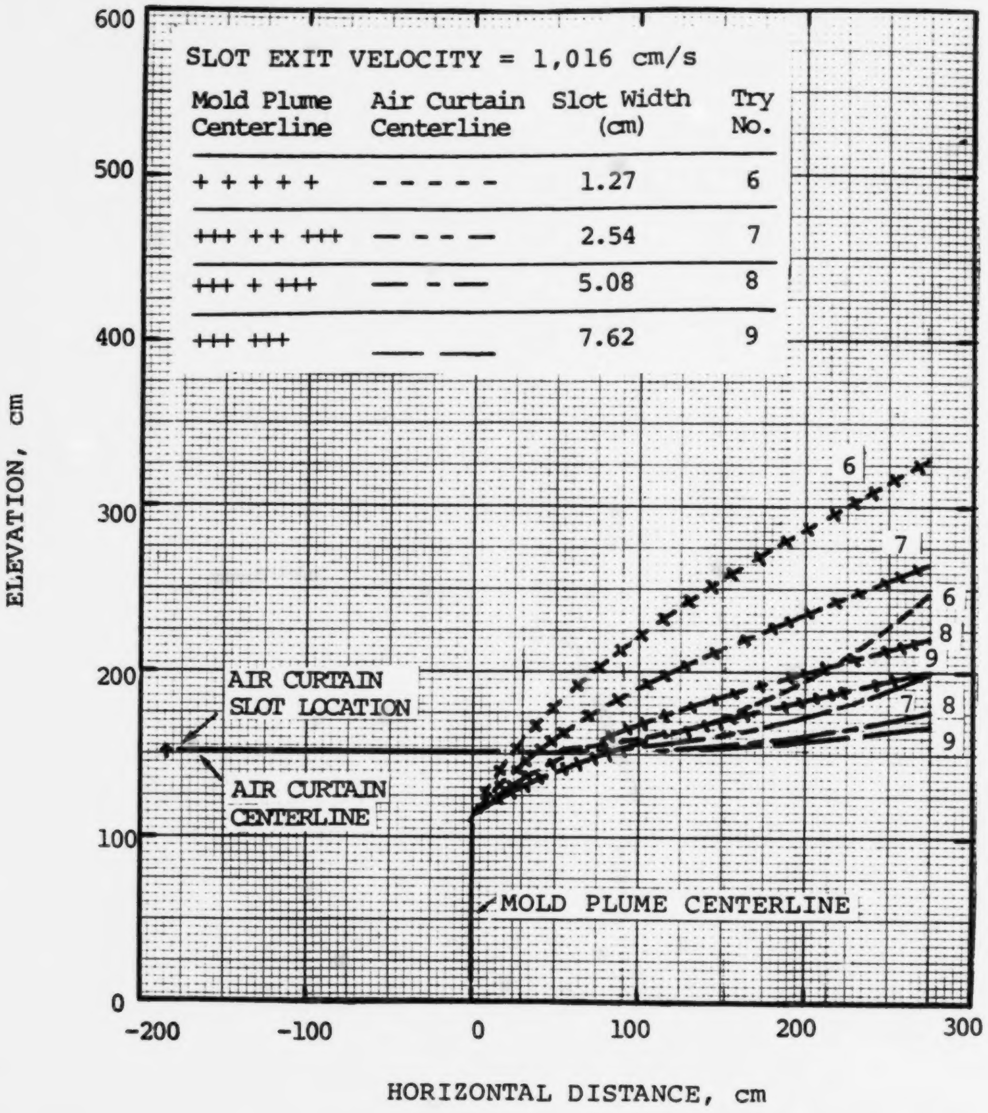


Figure 9. Theoretical mold plume and air curtain trajectories for constant slot exit velocity and various slot widths.

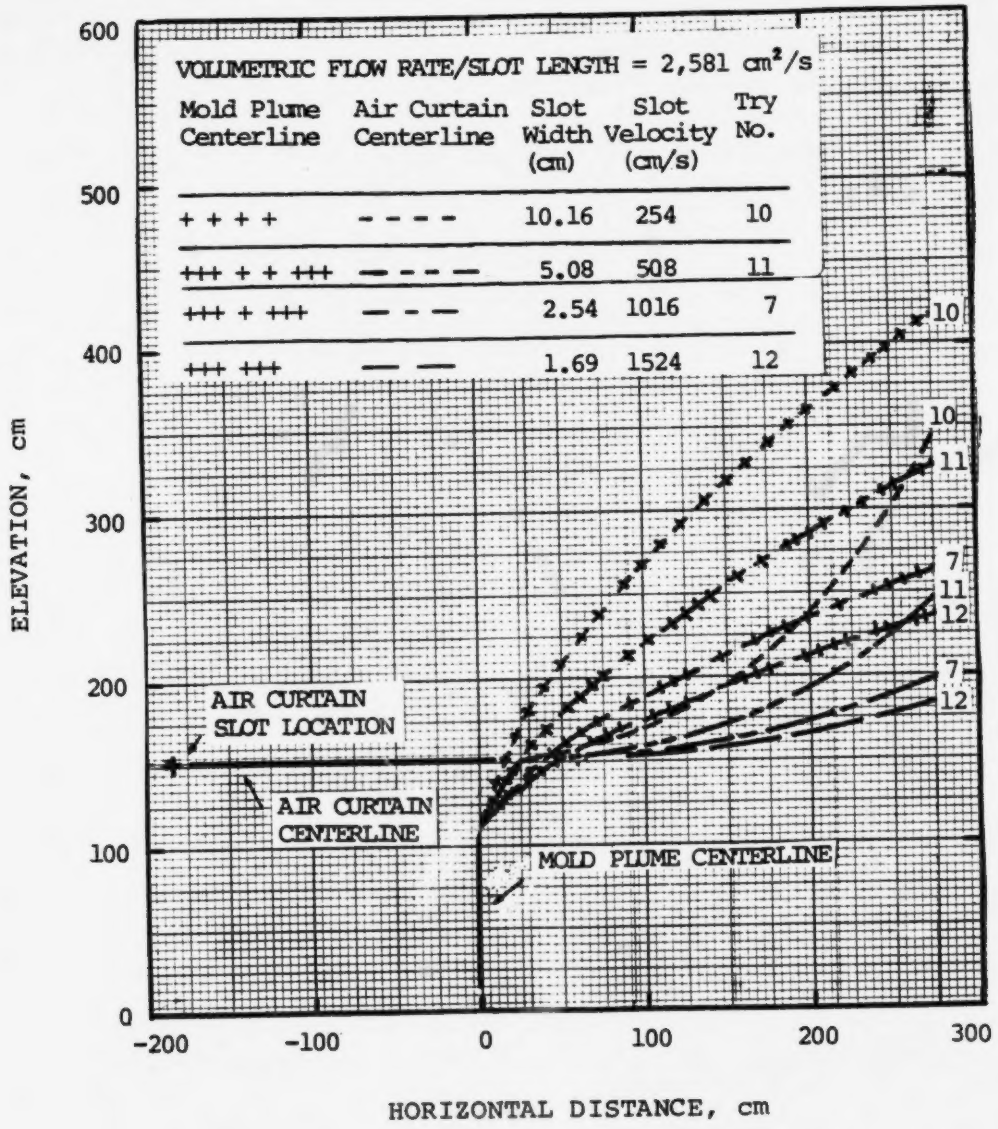


Figure 10. Theoretical mold plume and air curtain trajectories for various combinations of slot width and slot velocity that yield a constant volumetric flow rate.

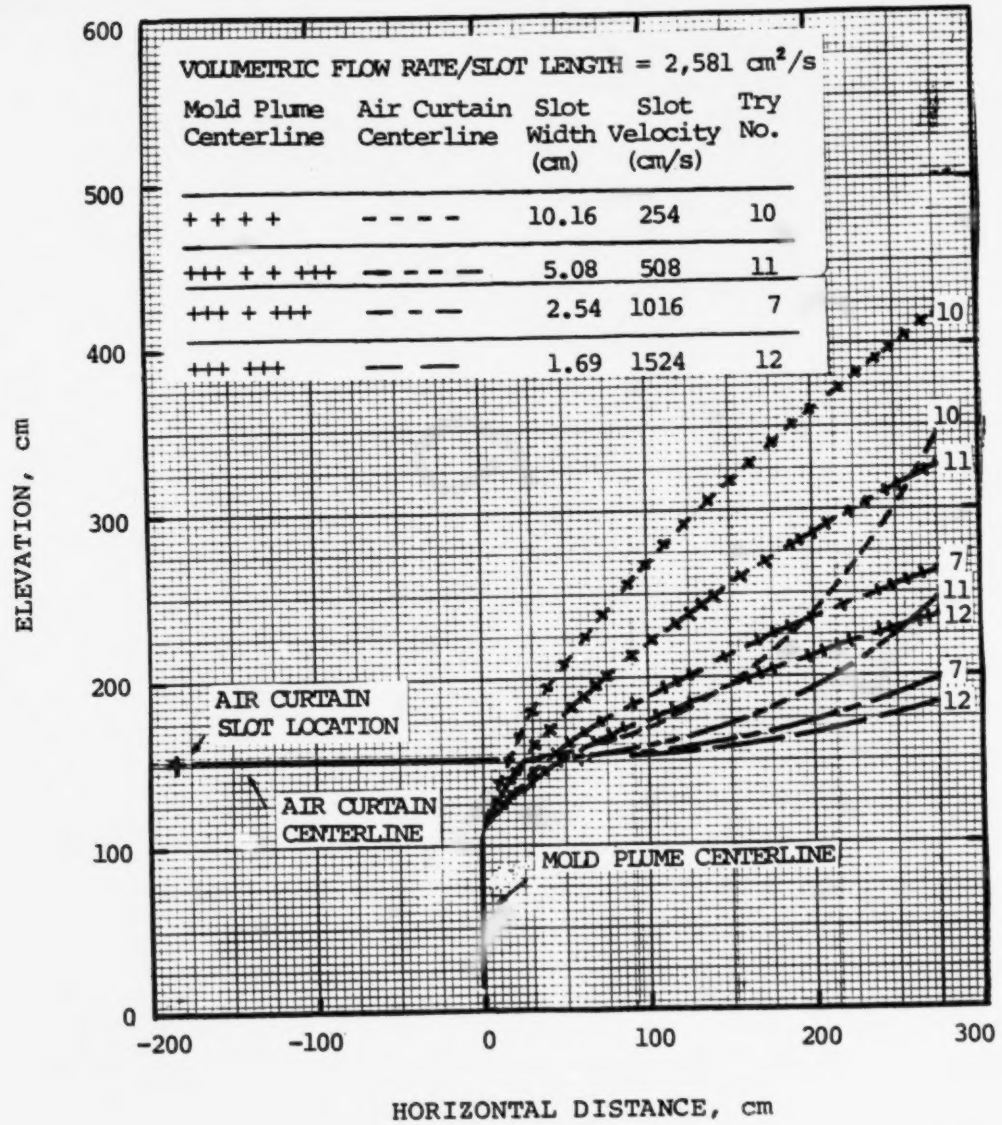


Figure 10. Theoretical mold plume and air curtain trajectories for various combinations of slot width and slot velocity that yield a constant volumetric flow rate.

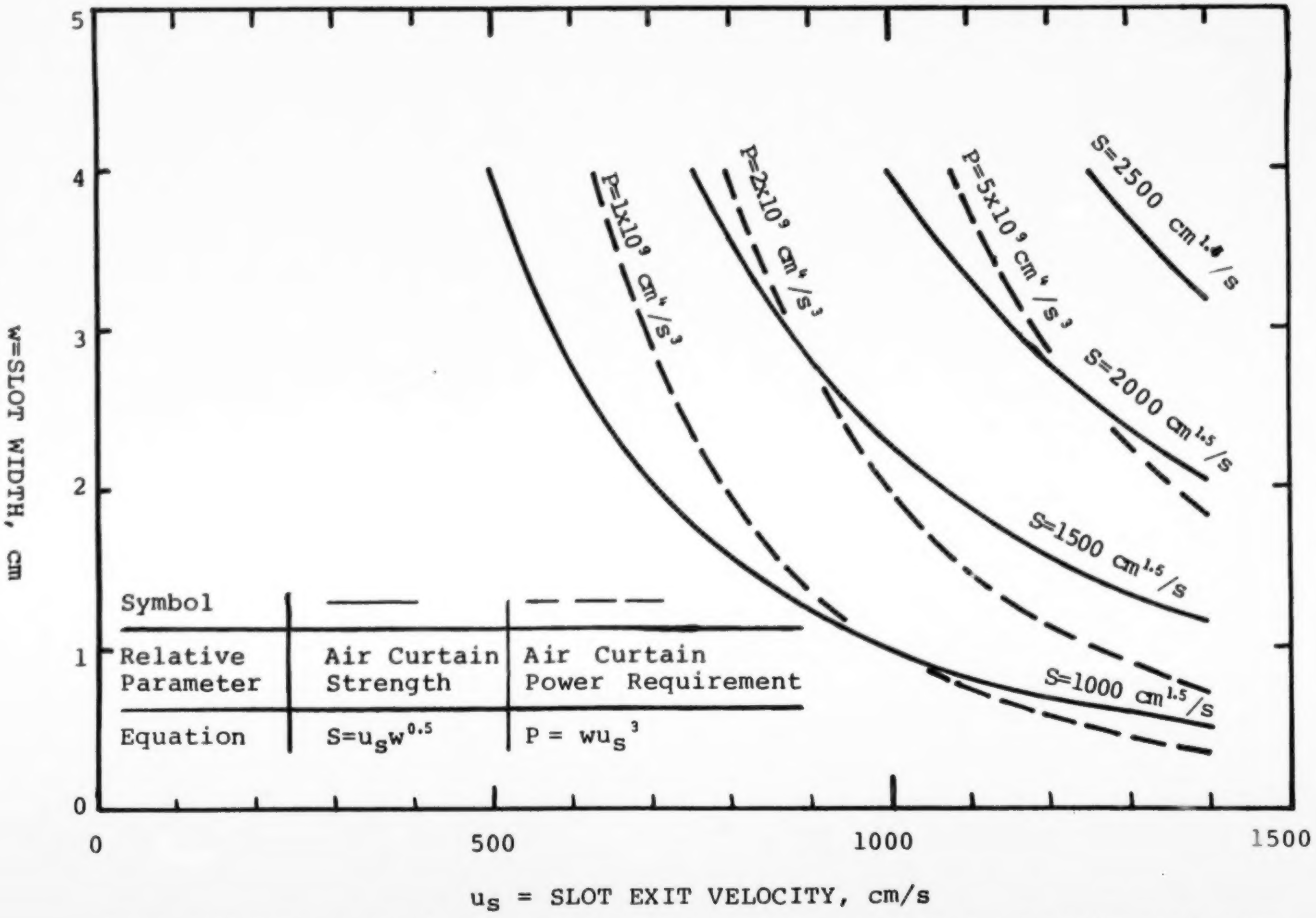


Figure 11. Air curtain power requirement and strength as functions of slot width and slot exit velocity.

(S) Value range = 1835 - 3670 $cm^{1.5}/s$
Slot width = 5.7 cm (2.25 in)
Slot exit velocity = 508 - 1524 cm/s (1000 - 3000 fpm)
Slot length = 152 cm (60 in)
Allowable Plume Drift = 23 cm (9 in) each side

DESIGN VERIFICATION TESTS

Apparatus

An air curtain from EPA Contract No. 68-02-3109 was modified according to the established design criteria to verify adequacy of the air curtain design previously described and to obtain design data for the particle collection device. The air curtain was tested at the demonstration site foundry and in the A.P.T. laboratory. The relative positions of the air curtain and the mold, are shown in Figure 12. The slot of the air curtain duct is horizontal.

In order to ensure that the air curtain unit was as flexible as possible for pilot plant operation, certain extra features were added. The air curtain support structure was made adjustable in elevation so that air curtain slot height was adjustable (by means of hand cranks) from 107 cm (3.5 ft) to 198 cm (6.5 ft) above the floor. The angle of discharge of the air curtain was also made adjustable.

Methods and Results

When the air curtain unit was first erected at the demonstration foundry using an actual mold, visual inspection indicated that smoke from the mold was captured completely and conveyed in a horizontal manor. However, the smoke was present only in small concentrations, which made it difficult to determine the amount of plume spreading within the air curtain.

Laboratory experiments were conducted to determine the horizontal and vertical expansion of the air curtain and smoke. This information is needed in sizing the particle collection device. Mold emissions were simulated with burning paper. Horizontal and vertical expansion of the air curtain was

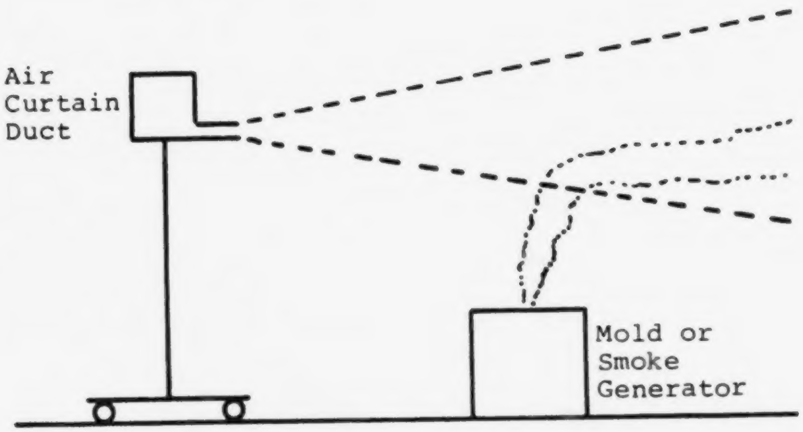

Air
Curtain
Duct
Mold or
Smoke
Generator

Figure 12. Air curtain design verification experiment arrangement.

determined by measuring the velocity profile of the air curtain at 4.0m (13 ft) downstream from the air curtain slot, which is the maximum distance expected for location of the particle collection device. Velocities were measured with a thermal anemometer. Air velocities were profiled near both the minimum and maximum slot velocities of the air curtain design range.

The velocity profile for maximum slot velocity is illustrated in Figure 13. The average velocity of this profile is 234 cm/s (460 fpm), which agreed exactly with the theoretical prediction of 234 cm/s (460 fpm). The profile of Figure 13 also revealed that the height of the air curtain is 180 cm (6 ft) and its width was also 180 cm (6 ft). At 4.0 m (13 ft) from the air curtain slot, the portion of the air curtain that contained smoke had a height of 180 cm (6 ft) and a width of 120 cm (4 ft).

Based on these test results we concluded that the air curtain design was adequate.

FILTER UNIT

Selection of Collection Mechanism

Fugitive mold emissions had a mass median diameter of 0.2 to 0.4 μmA. Due to the low concentrations of emissions, the water requirements, and complicated nature of the SCAT, the charged spray scrubber was determined to be an ineffective system for our application. With the approval from the EPA, a filtration system was used instead. In selecting the particle collection device to be used, two varieties of filter units were considered: HEPA (High Efficiency Particulate Air) filters, and fabric bag filters. HEPA filters were selected because: (1) they require less space than the fabric bags would have and (2) they are much more efficient for collection of particles in the size range to be encountered. In order for typical bag filters to be more than about 20 percent efficient for 0.2 to 0.4 μmA sized particles they must first establish a dust cake which itself accounts for the improved efficiency on fine particles. The HEPA filters use

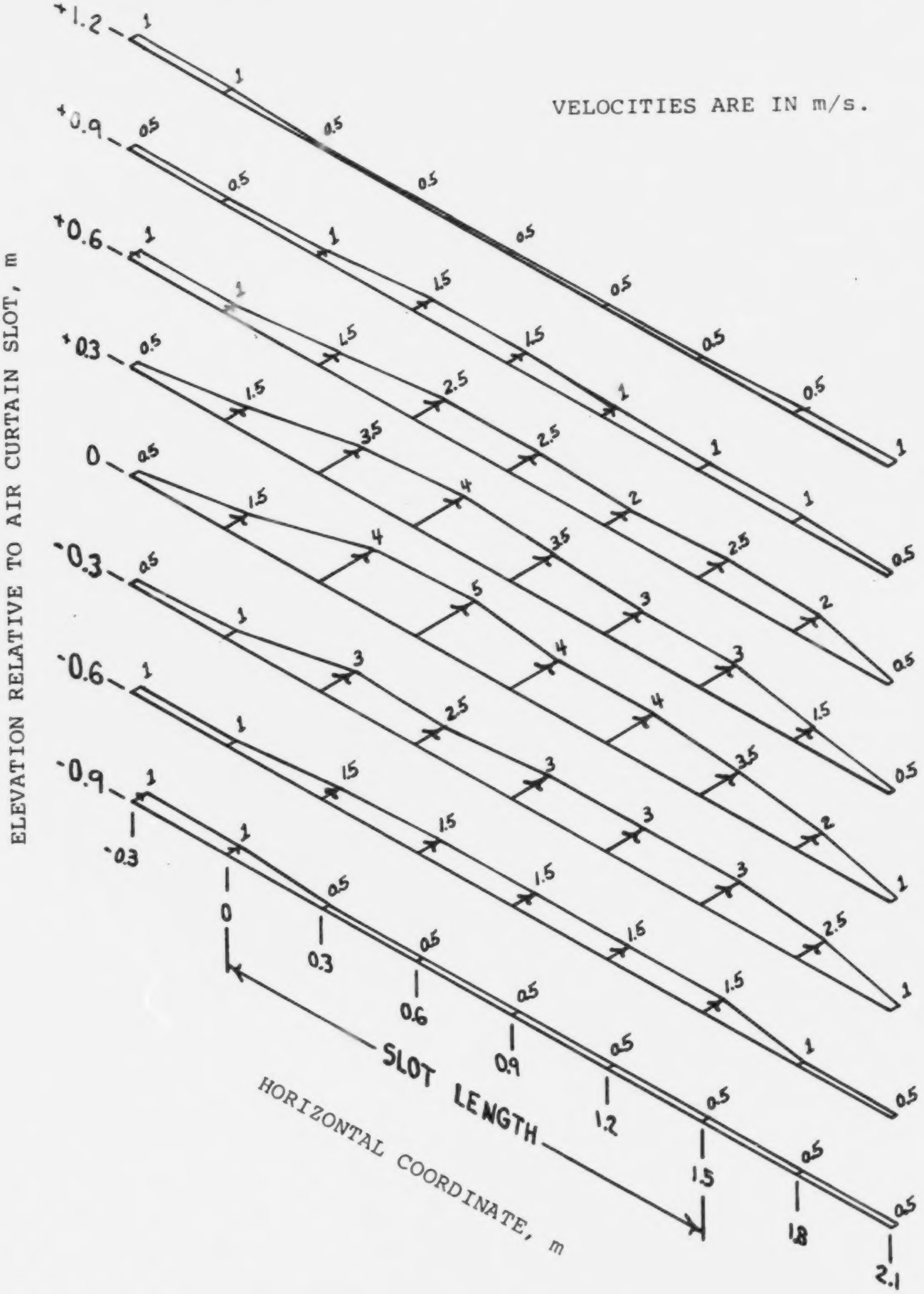


Figure 13. Velocity profile at 4.0 m (13 ft) from air curtain slot. Slot exit velocity is 15 m/s (2900 fpm).

glass microfiber paper that is pleated. Two types of HEPA filters were considered for this application: series 95 and series 100.

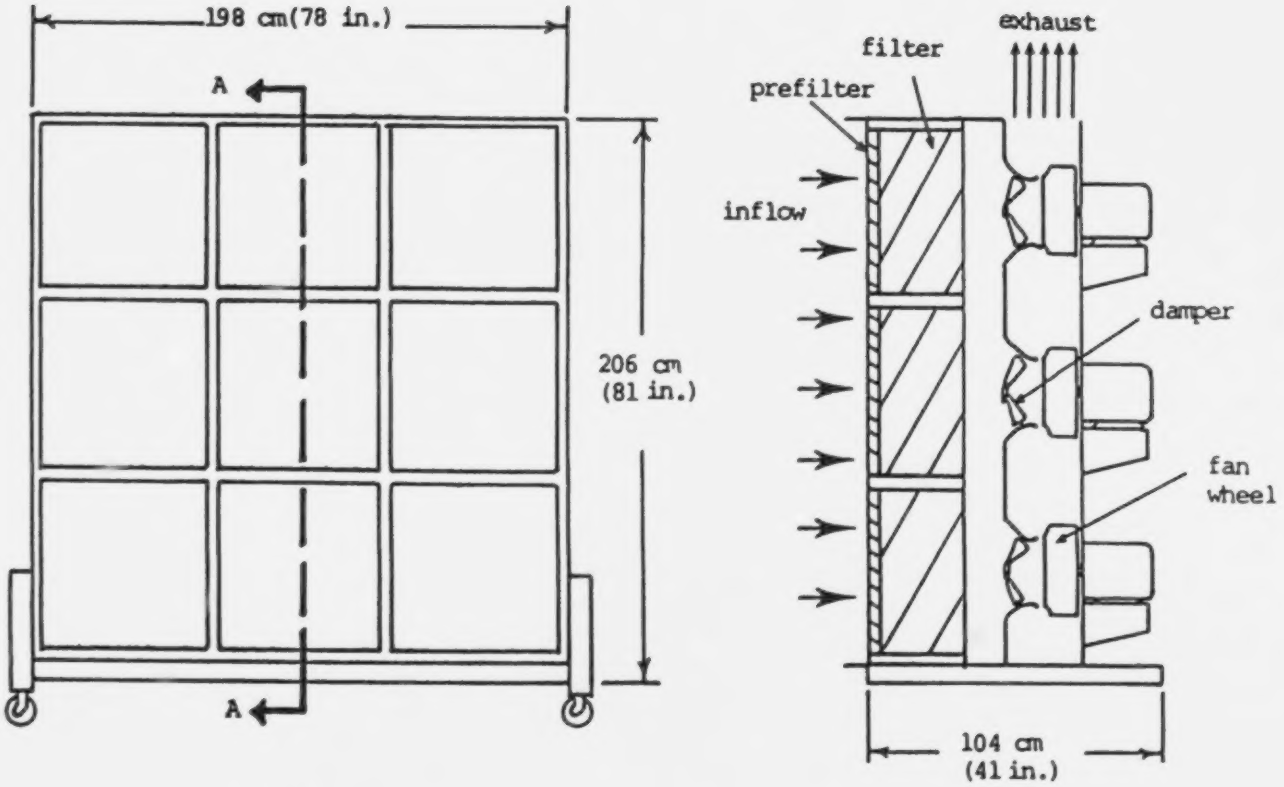
Series 95 filters have a maximum facial velocity rating of 254 cm/s (500 fpm), and have a collection efficiency of 95% when tested with 0.3 micrometer thermally generated dioctylphthalate (DOP) smoke, in accordance with Federal Standard 209B. Estimated overall collection efficiency for the series 95 filters on mold emissions was 90%.

Series 100 filters have a maximum facial velocity rating of 140 cm/s (275 fpm), and have a collection efficiency of at least 99.97% when tested with 0.3 micrometer thermally generated DOP smoke. Estimated overall collection efficiency for these filters on mold emissions was 98%.

Maximum expected air curtain velocity approaching the particle collection device is 242 cm/s (476 fpm). To match this velocity, the series 95 filters were selected. Series 100 filters would have excessive pressure drop and reduced efficiency if operated at the expected inlet air velocities of the pilot plant. The 100 Series filters could have been used if a larger bank of them were enclosed in a housing with a reduced diameter inlet sized so that the filter unit accepted the air curtain jet isokineticaly. This would of course be more expensive.

The filter unit used in the pilot plant is illustrated in Figure 14. To form a 183 cm by 183 cm (6 ft by 6 ft) filter panel, nine filter modules, each 61 cm by 61 cm (2 ft by 2 ft), were used. The depth of the HEPA filter modules is 29.2 cm (11.5 in). A medium efficiency prefilter, of pleated paper media and 5 cm (2 in) deep, was used upstream of each HEPA filter to extend the usable service life of the units. A wire grill was installed in front of the prefilters to act as a protective shield for the inlet area of the filter bank.

The enclosure for the particle collection filter bank is illustrated in Figure 15 and was constructed from the following major carbon steel elements: 7.6 cm (3 in) channel, 3.8 cm x 0.17 cm (1.5 in x 0.065 in) square tubing, 0.15 cm (0.060 in) thick


198 cm(78 in.)
A
A
206 cm
(81 in.)
exhaust
filter
prefilter
inflow
damper
fan
wheel
104 cm
(41 in.)

FRONT VIEW

SECTION A-A

Figure 14. Filter unit of pilot plant.

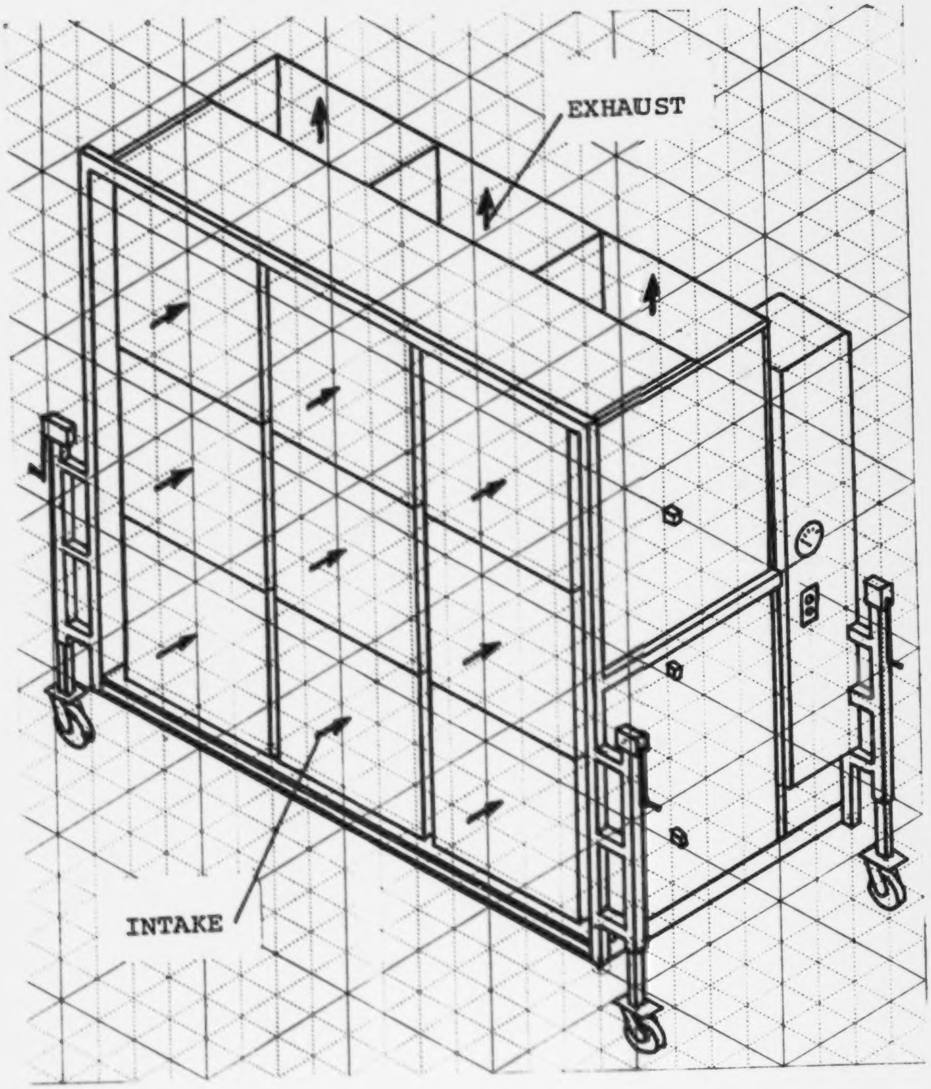

EXHAUST
INTAKE

Figure 15. Pilot plant filter unit.

sheet, and 2.5 cm x 2.5 cm x 0.32 cm (1 in x 1 in x 0.125 in) angle. The support structure for the collection device was designed with adjustable legs which allow the elevation of the center of the filter unit to vary between 107 cm (3.5 ft) and 198 cm (6.5 ft) above the floor, by means of hand cranks.

Selection of Fan Arrangement

To move air through the particle collection filters, suction fans were used downstream of the filters. Maximum volumetric flow rate for the filter unit is 9.4 m^3/s (20,000 cfm), and the maximum pressure rise for the fans is 13 cm W.C. (5 in W.C.).

Several alternative designs were considered for the fans including fans built into the filter assembly and fans separate from the filter assembly. Also, various types (plug, air kit, belt driven, and direct drive) were considered.

The selected arrangement was nine, direct drive, centrifugal, plug type fans built directly into the filter bank assembly. This design minimizes the size of the pilot plant apparatus and permits flexibility in matching filter inlet velocities to the air curtain velocities. The design of the filter unit is shown in Figure 15. The nine fan motors are controlled by one pair of start-stop buttons, nine motor selector switches, and nine magnetic motor starters. The pressure drop of the filters is indicated by a magnehelic gauge. There are nine fan dampers that are controlled by 3 separate linkages: one for the bottom 3 dampers, one for the middle 3, and one for the top 3.

SECTION 5
PILOT PLANT TESTS

PURPOSE

Overall performance of the fugitive emission control pilot plant depends on both the ability of the air curtain unit to capture and convey the fugitive particles and the ability of the particulate control filter unit to collect the particles. Consequently, two test regimes were used to evaluate pilot plant operation: air curtain capture efficiency tests, and filter collection efficiency tests.

AIR CURTAIN CAPTURE EFFICIENCY TESTS

Method

To determine air curtain capture efficiency, which is the measure of the ability of the pilot plant's air curtain to capture the plume of a foundry mold, the mold emission rate and the portion of this emission captured by the air curtain needs to be known. Mold emission rate varies widely from mold to mold, and cannot be measured while the pilot plant is operating. Thus, using the emitted particles to determine capture efficiency is not feasible.

Particles emitted from the molds are small, and consequently behave in a manner similar to a gas. Therefore, the air curtain capture efficiency was determined using sulfur hexafluoride (SF_6) as a tracer gas to follow the path of the mold plume. The tracer gas SF_6 is chemically inert, physiologically inert, nonflammable, and noncorrosive with a viscosity that is approximately the same as that of air.

The tracer gas method for measuring air curtain capture efficiency is illustrated in Figure 16. A mixture of SF_6 (of a certified concentration) in air, is discharged upwardly into the mold plume from a 4 port manifold at a uniform, measured flow rate. The discharge locations are centered 30 cm (1 ft) above

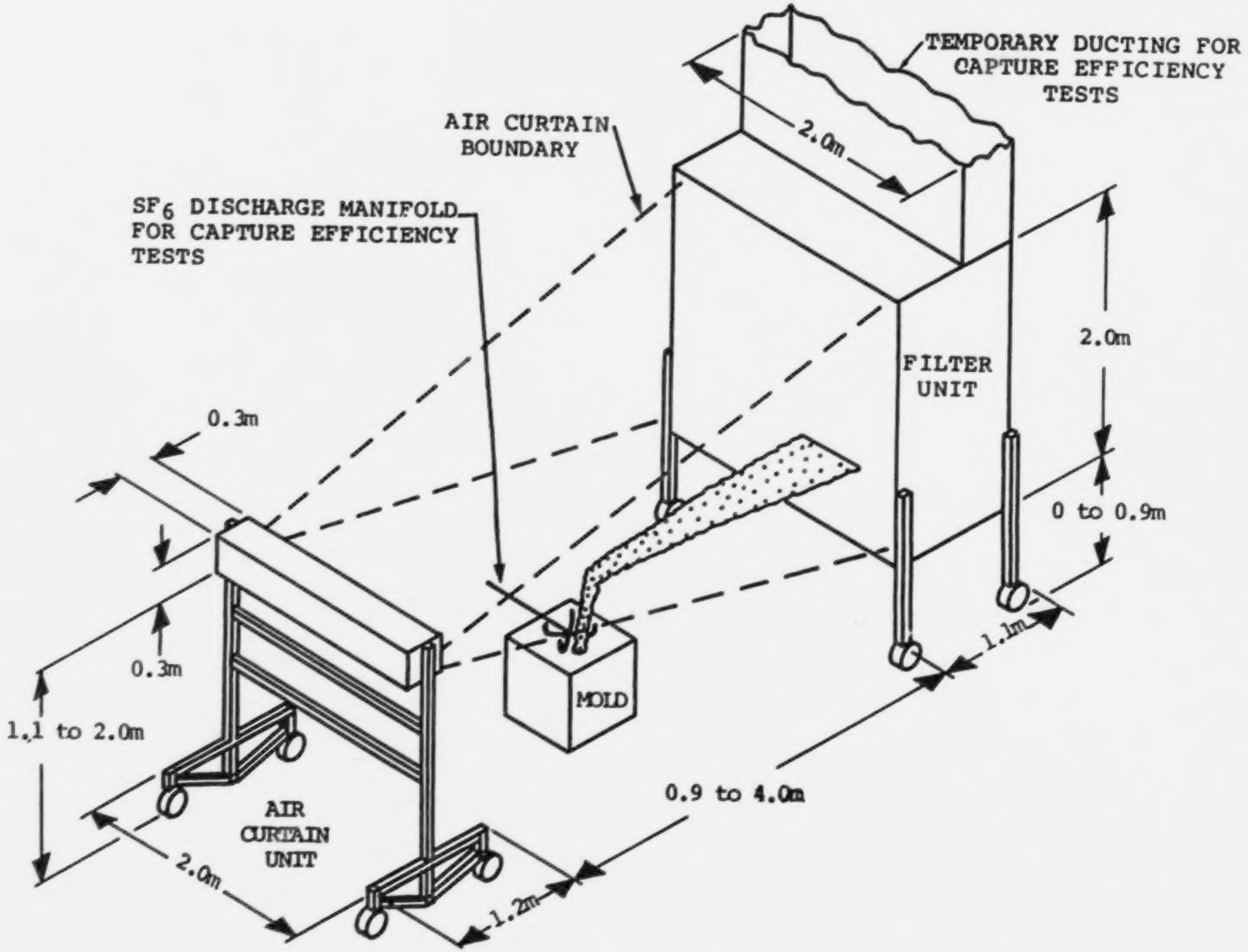

TEMPORARY DUCTING FOR CAPTURE EFFICIENCY TESTS
2.0m
AIR CURTAIN BOUNDARY
SF6 DISCHARGE MANIFOLD FOR CAPTURE EFFICIENCY TESTS
2.0m
FILTER UNIT
0.3m
0 to 0.9m
1.1m
MOLD
0.3m
1.1 to 2.0m
0.9 to 4.0m
AIR CURTAIN UNIT
2.0m
1.2m

Figure 16. Pilot plant arrangement for testing.

the mold in order to avoid flames that may be at the top of the mold. Also, the temperature and velocity of the SF_6 is matched to the temperature and velocity typical of the mold plumes.

A temporary duct of rectangular cross section was added at the filter unit outlet for SF_6 sampling and velocity measurements of the output of the particle collection device and is illustrated in Figure 17. This duct exhausts into existing foundry hooding that carries the exhaust to an outdoor location where the SF_6 cannot return to the air curtain area. The upper end limit for the pilot plant flow rate was determined by the maximum flow rate of the hooding system.

The temporary duct was fitted with a six column point by a four row point equally spaced array sampling. These twenty-four traverse points were used to accumulate duct velocity information and duct tracer gas samples in order to determine the overall filter unit flow rate and duct tracer gas concentration. Velocity sampling was executed with a standard pitot tube at each matrix point, and SF_6 tracer gas samples are drawn from each matrix point through use of 20 cm^3 syringes. The SF_6 concentrations of the gas samples were measured with an electron capture gas chromatograph which was calibrated (with certified concentrations) at the beginning, middle and end of each data reduction run. The pitot tube pressure readings and SF_6 concentrations as well as SF_6 injection rate, duct pressure and temperature, and all atmospheric conditions for each test were entered into a computer data reduction program. Computer analysis resulted in an output of gas velocities, and the volumetric flow rate of the filter unit, and the overall capture efficiency of the air curtain unit. Air curtain capture efficiency is calculated according to the following definition:

$$\text{Air Curtain Capture Efficiency} = \frac{\text{Total volumetric flow of } SF_6 \text{ measured at filter unit outlet, at standard temperature and pressure}}{\text{Volumetric flow of } SF_6 \text{ injected above the mold, at standard temperature and pressure}}$$

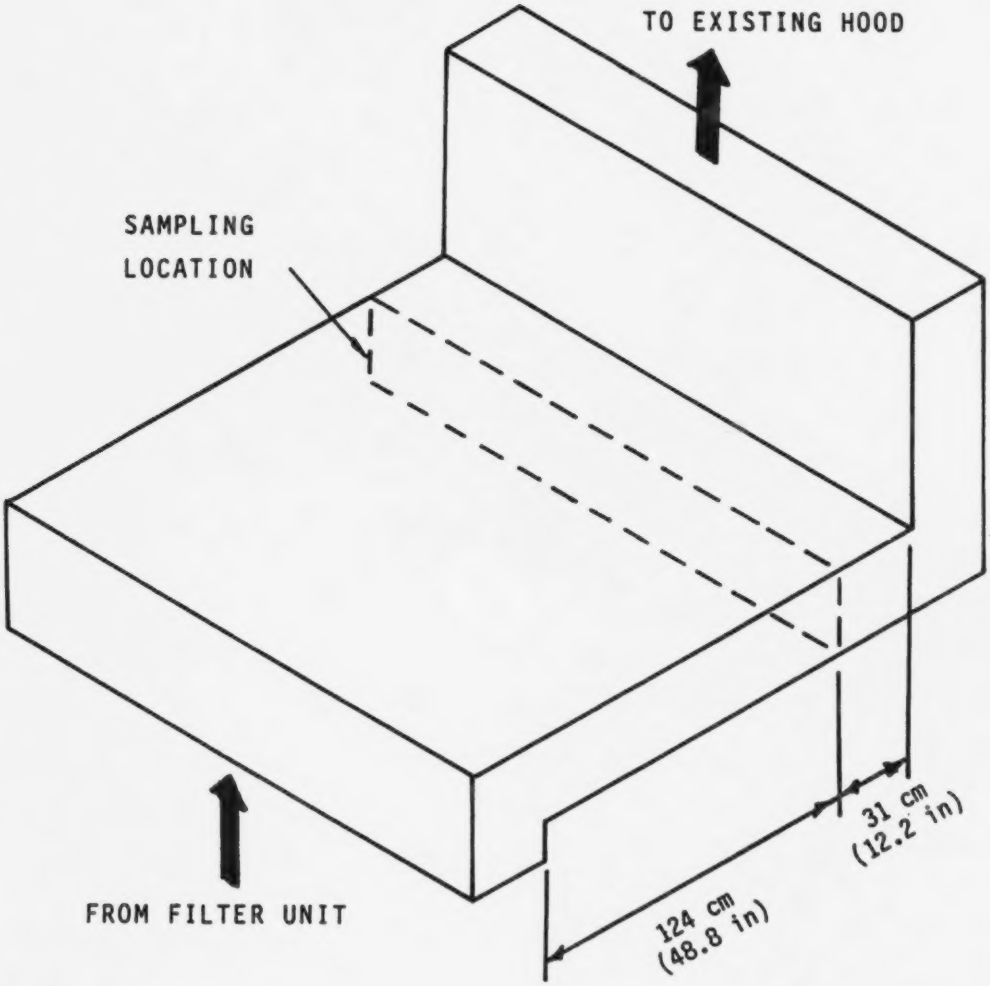

TO EXISTING HOOD
SAMPLING LOCATION
FROM FILTER UNIT
124 cm (48.8 in)
31 cm (12.2 in)

Figure 17. Temporary sampling duct for filter unit.

For all of the capture efficiency tests, the air curtain unit was located 370 cm (12 ft) from the filter unit. The air curtain slot height from the ground is set by the height of the mold, with the convention that the curtain wedge of air is not to impact the surface of the mold. The air curtain unit itself is centered horizontally with respect to the horizontal center-line of the filter unit. The air curtain unit is also aligned vertically so that its slot output is aimed directly at the vertical centerline of the filter unit. The volumetric flow rate of the filter unit is set at nominally 115% of that of the air curtain flow field at the filter unit inlet.

The normal sequence of a capture efficiency test is initiated after all equipment has been set up and aligned, and the mold has been poured. First, background air samples are taken in the areas of the air curtain, the filter unit, and inside the sample duct. The pilot plant is then turned on, and SF_6 injection is initiated. Sampling begins only after the control equipment and the SF_6 injection have reached steady state conditions. Gas samples are drawn in a random order from the sample matrix to reduce any systematic errors, with some replicate samples being taken. Velocity measurements were taken one matrix column at a time in a random order. SF_6 injection parameters were repetitively monitored over the course of the test, at which times background samples from the air curtain inlet area were also taken. Midway through the test sequence, a complete set of 5 background samples were taken around the face perimeter of the filter unit to determine if any SF_6 escaped capture by the air curtain wedge. Another set of background samples were taken near the air curtain and filter bank as well as from inside the sample duct after completion of all test activities.

Performance Results

A total of 18 air curtain capture efficiency tests using SF_6 were performed on the pilot plant unit situated at the Navy foundry demonstration site. Of those 18, 7 were observed to have either unusually high background concentrations of SF_6 indicating leakage of some sort or critical equipment failure related to the pilot plant or its associated test equipment. We concluded that those 7 tests were not representative of pilot plant performance.

The remaining eleven test runs are summarized in Table 11 and presented graphically with a least squares linear regression fit line in Figure 18. The measured capture efficiency varied from a low of 63.4% to a high of 105.0%, while the average air curtain slot velocities varied from a low of 1653 ft/min to a high of 2662 ft/min. The values that lay between these extremes can be seen to exhibit a general trend of increasing air curtain capture efficiency with increasing air curtain exit slot velocity, up to a maximum level. For the particular pilot plant arrangement at the demonstration site, the data indicates that the slot velocity for maximum air curtain capture efficiency of the mold plume is in the range of 2,400 to 2,700 ft/min. The computer information reduction sheets which generated this information as well as all pertinent test data on each particular test set-up (mold size, material, weight, arrangements, etc.) are presented in Appendix A.

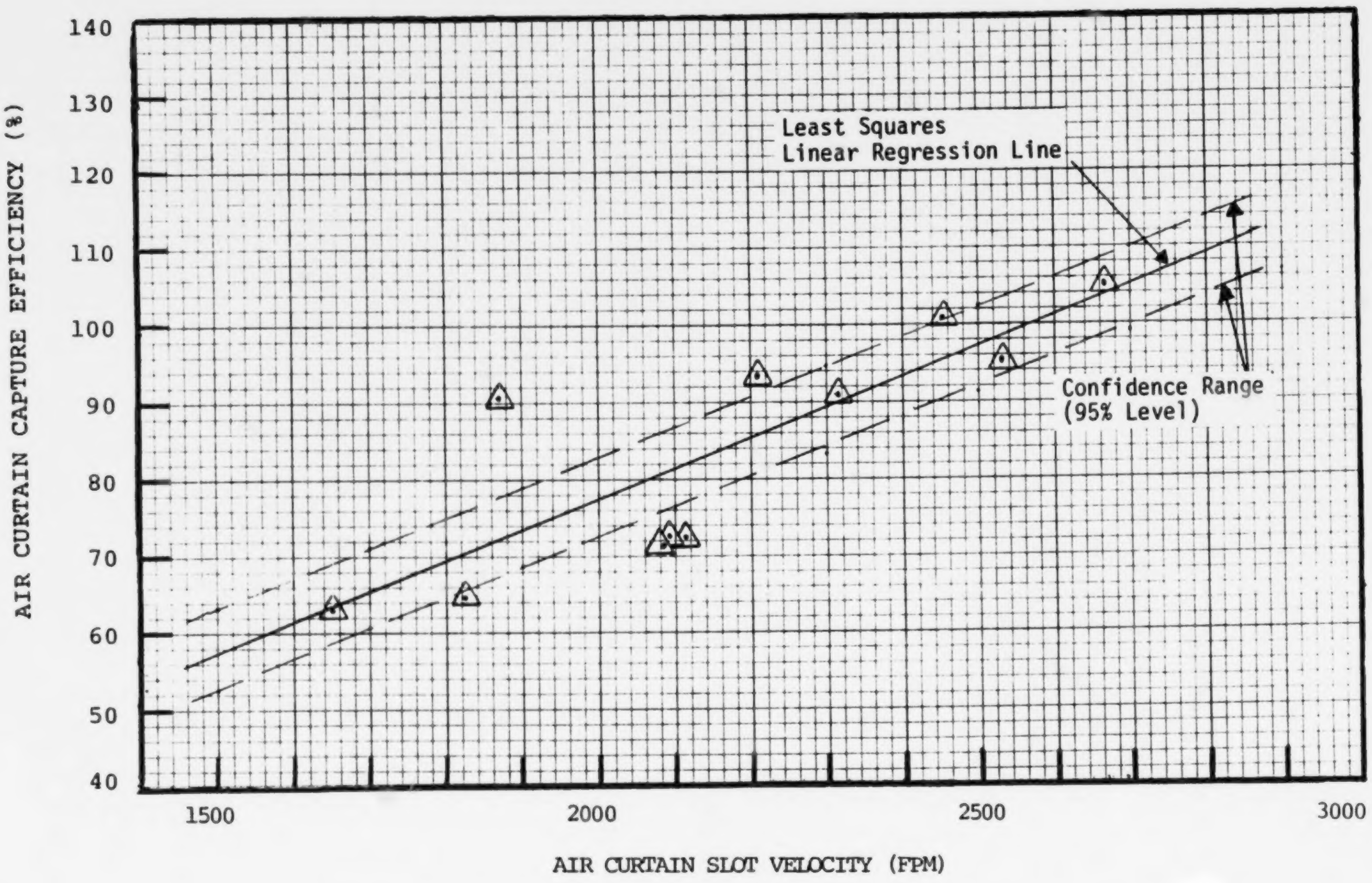


Figure 18. Air Curtain Capture Efficiency.

TABLE 10. Air Curtain Capture Efficiency Tests

Run No.	Average Air Curtain Slot Velocity (cm/s)	Average Air Curtain Slot Velocity (ft/min)	Q_{fu}/Q_{ac} (%)	Capture Efficiency (%)
22-01	1352	2662	105	105.0
27-01	1058	2083	120	71.6
27-02	1176	2314	112	91.0
28-02	950	1870	125	90.5
28-03	840	1653	127	63.4
28-04	1063	2093	105	74.4
29-01	1287	2534	109	95.4
29-03	1074	2115	111	72.1
29-04	925	1821	118	64.5
30-01	1122	2209	121	93.4
30-02	1247	2454	111	100.6

Q_{fu} = Filter Unit Inlet Volumetric Flow Rate

Q_{ac} = Air Curtain Volumetric Flow Rate at Filter Unit Inlet

FILTER COLLECTION EFFICIENCY TESTS

Method

In order to measure collection efficiency of the particle control filters used in the pilot plant unit, it is necessary to measure the particle concentrations present in both the inlet and outlet air streams of the pilot plant unit. Particle concentrations at the inlet and outlet of the pilot plant filter unit are too low to allow measurement of the particle concentrations by direct measurement in-situ. Consequently, a small scale unit was developed to duplicate the pilot plant unit, incorporating the same filters and filter surface velocities while minimizing dilution of the mold emissions.

Filter collection efficiency sampling equipment arrangement is shown in Figure 19. A small series 95 HEPA filter, 30 cm by 30 cm by 29 cm deep (12 in by 12 in by 11.5 in deep) was

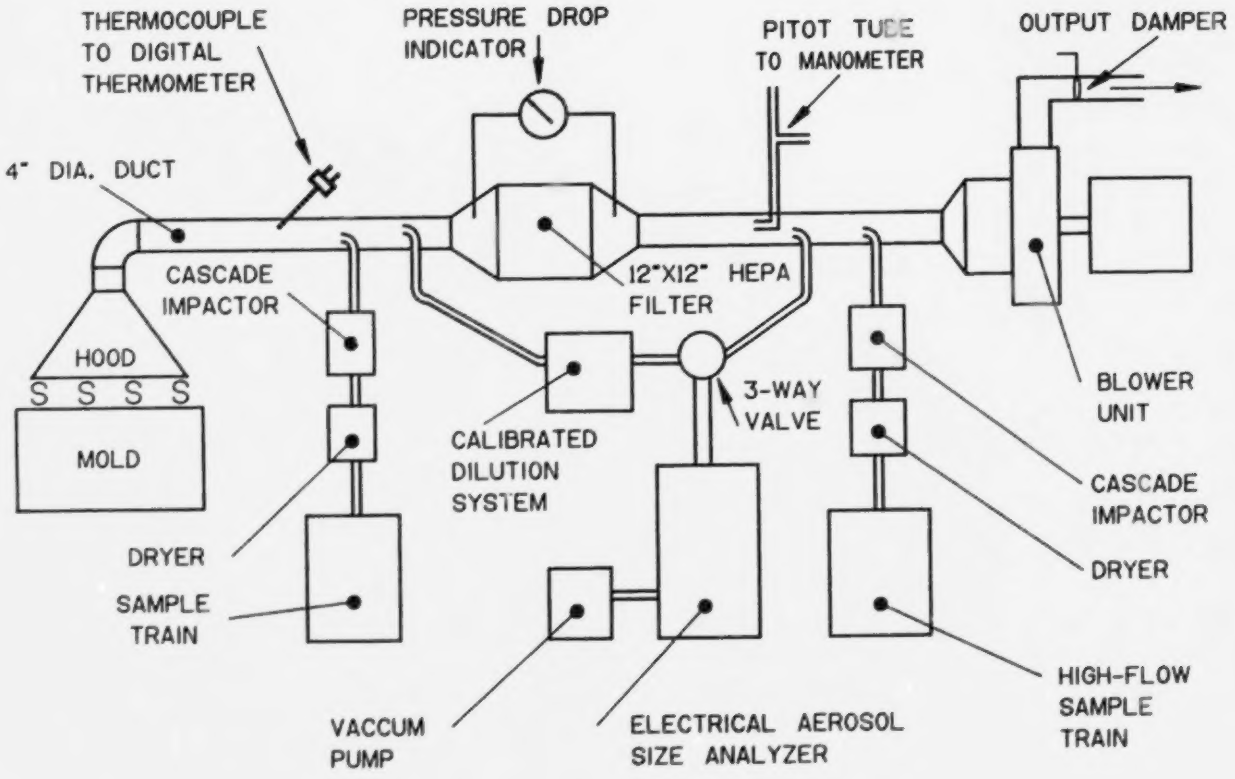

THERMOCOUPLE
TO DIGITAL
THERMOMETER
PRESSURE DROP
INDICATOR
PITOT TUBE
TO MANOMETER
OUTPUT DAMPER
4" DIA. DUCT
CASCADE
IMPACTOR
HOOD
S S S S
MOLD
DRYER
SAMPLE
TRAIN
12"X12" HEPA
FILTER
CALIBRATED
DILUTION
SYSTEM
3-WAY
VALVE
BLOWER
UNIT
CASCADE
IMPACTOR
DRYER
HIGH-FLOW
SAMPLE
TRAIN
VACCUM
PUMP
ELECTRICAL AEROSOL
SIZE ANALYZER

Figure 19 . Equipment Layout for Filter Efficiency Tests.

installed on a 4 in. ducting line in conjunction with a portable hooding system which captured the mold emissions. The system was driven by a blower unit with a variable output damper to adjust velocity to the same filter surface velocities as encountered in pilot plant operation. A standard pitot tube and inclined manometer were used to regulate the velocity of the system, while a k-type thermocouple with digital readout was used to monitor gas temperatures. Sample ports were installed both upstream (inlet) and downstream (outlet) of the filter unit at 8 diameters downstream from flow disturbances.

Fractional efficiency and particle size distributions were measured with both cascade impactors and an Electrical Aerosol Size Analyzer. Both methods incorporated an appropriate sample nozzle, in each of the two sample ports constructed, to sample isokineticaly. Cascade impactors were used to obtain data on the larger particles (greater than 0.5 μmA) of the mold plume, and the Electrical Aerosol Size Analyzer was used for the smaller particles (less than 0.5 μmA).

Cascade impactor sampling was performed in accordance with EPA Report Number 600/2-77-004 "Procedures for Cascade Impactor Calibration and Operation in Process Streams" using University of Washington Mark III Cascade Impactors. Gas samples enter at the sample nozzle, and pass through the impactor stages where particles are separated by inertia. The cascade impactors for inlet sampling contained 7 stages. The outlet impactors contained only 5 stages in order to increase the sampling rate to compensate for lower outlet particle concentrations. All cascade impactor stages had particle collection plates lined with greased aluminum foil. Gas leaves the impactor, passes through a weighed drier to remove traces of moisture, and is delivered to a sample train unit where the dry gas volume is measured by a rotometer and an integrating dry gas meter in the gas flow rate control module. A vacuum pump is used to pull gas through the system. Data is obtained by computer reduction of the mass gains as a function of impactor stage and knowledge of the information obtained during operation of the calibrated sample train unit.

Smaller particles were measured with a Thermo-Systems Model 3030 Electrical Aerosol Size Analyzer (E.S.A.). Inlet gas samples enter the sample nozzle and are passed through a precision calibrated dilution system (to dilute the raw mold plume to levels acceptable to the E.S.A.), through a 3-way selection valve, and into the E.S.A.. To sample the outlet concentrations, the 3-way valve is positioned to draw gas from the outlet sample nozzle and deliver it to the E.S.A.. The E.S.A. unit is based on the "diffusion charging-mobility analysis" principle. It measures the number of particles larger than 7 particle diameters, ranging from 0.01 to 0.32 μm. A vacuum pump is used to pull gas through the system. The information generated by the E.S.A. is converted to particle concentrations as a function of the particle step sizes.

Results

A total of 3 mold plumes were profiled in order to determine particle collection efficiency of the HEPA filters. Results are graphed by particle penetration (%) as a function of mean particle diameter (μm). Efficiency is determined by the following formula: Efficiency = 1 - Penetration.

Results of the cascade impactor sampling are shown in Figure 20. Data presented in Figure 20 does not reveal an obvious penetration trend, with values shown of between .01% to above 50% penetration. The most probable explanation for the scattering of data points originates in the method used to determine this range of particle size penetration. The basic methodology of cascade impactor use centers about information obtained on the relative weight gains of each stage's impaction substrate. It is the particle accumulations which reveal concentrations by particle size. In the filter efficiency tests performed, most of the weight gains of the substrates were in the range of 0.1 mg which, unfortunately, is within the error range of the electronic scale being used to weigh them. This fact lends obvious uncertainty to the data, whose accuracy can then be called into question.

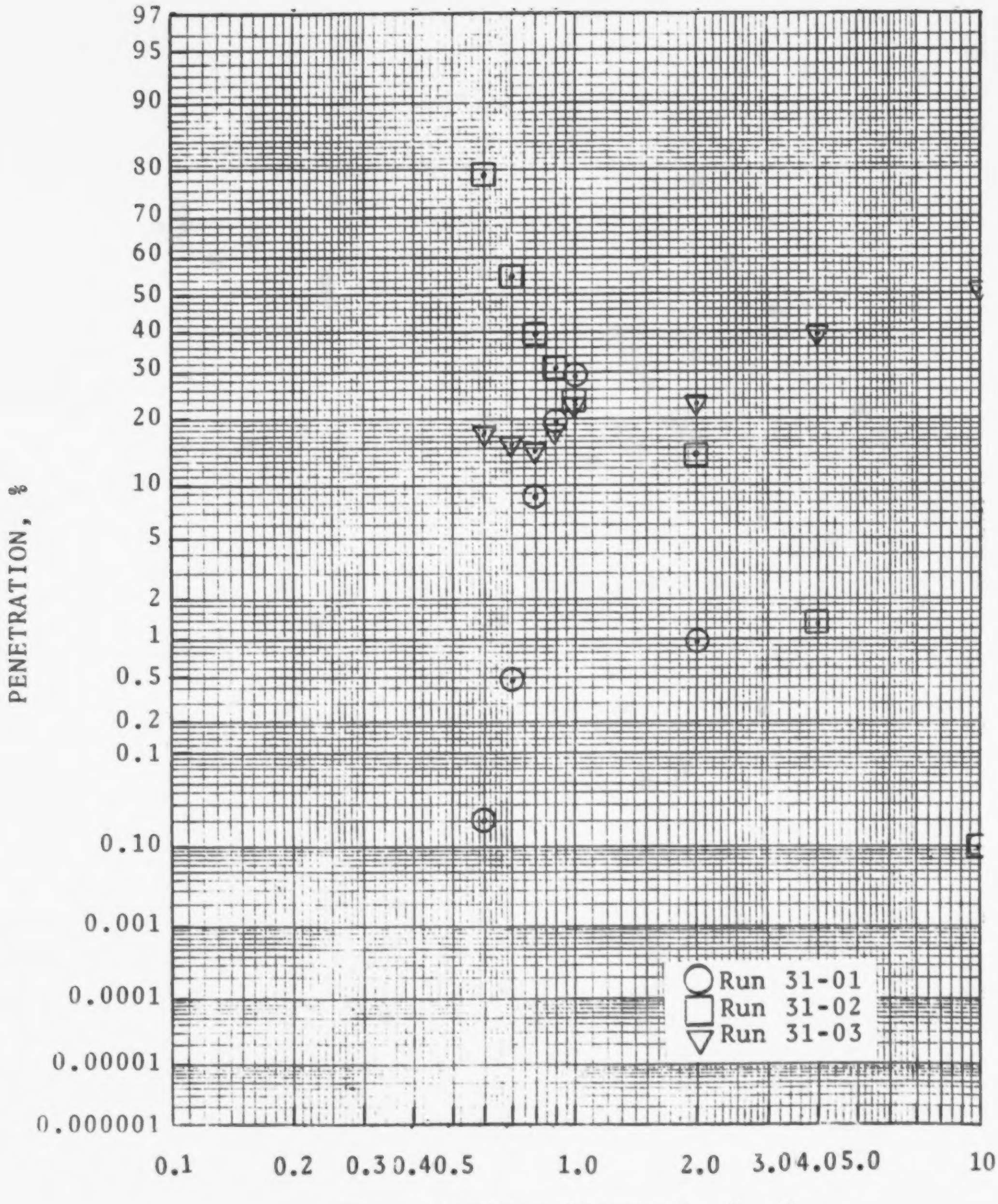


Figure 20. HEPA Filter Penetration by C.I.

Results of electrical aerosol size analyzer sampling are shown in Figure 21. An obvious trend is visible in the E.S.A. data which shows that measured penetration is less than 1% for particles between 0.1 and 0.4 µmA diameter, indicating better collection efficiency (99+%) than anticipated by the 95% rating at 0.3 µm of the HEPA 95 filters.

Computer calculation data for cascade impactor sampling and for E.S.A. sampling as well as mold data (dimensions, weight, type, etc.), are presented in Appendix B.

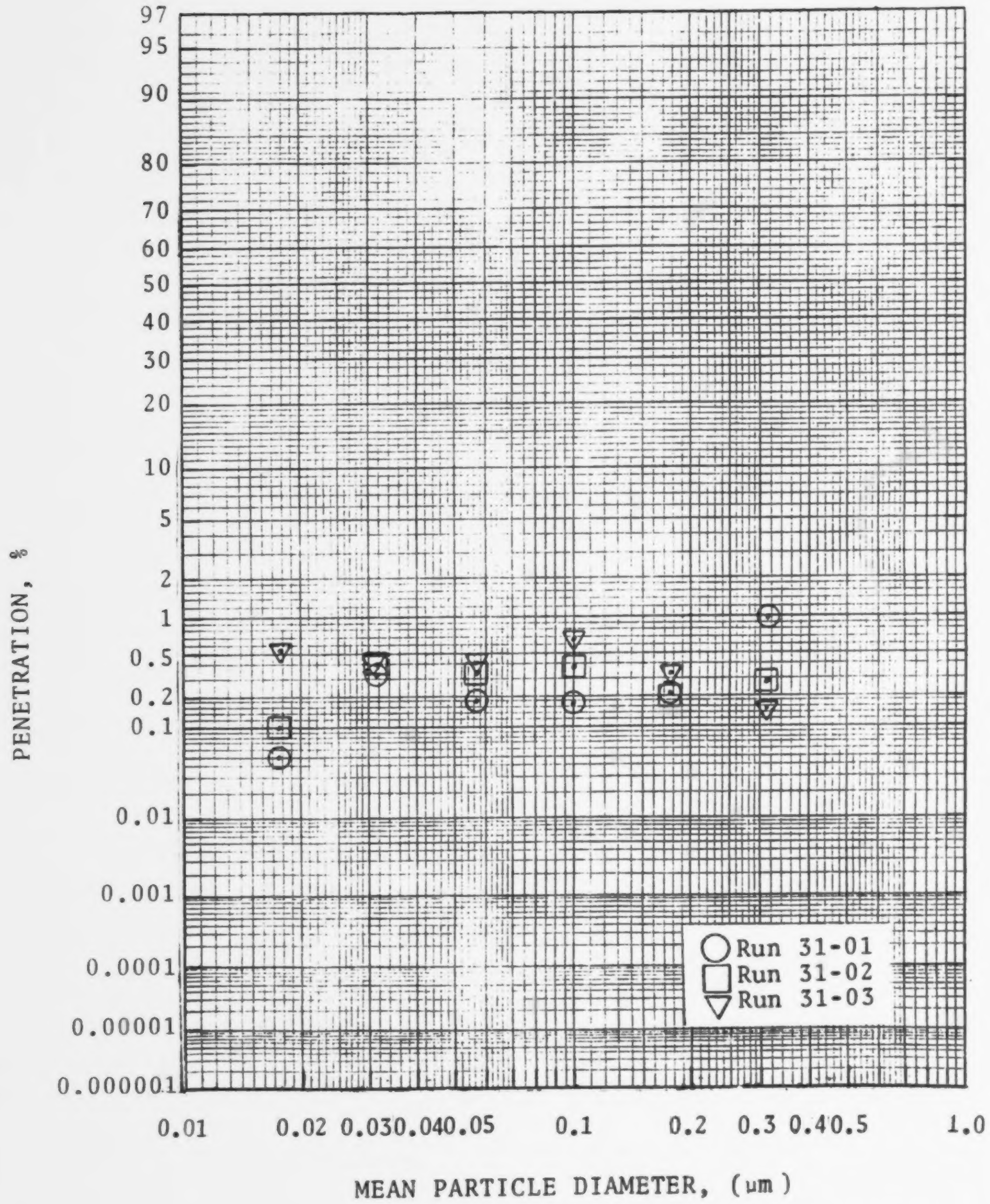


Figure 21. HEPA Filter Penetration by E.S.A

SECTION 6

CONCLUSIONS

The air curtain transport system, designed and installed as a pilot plant at a demonstration foundry, provides an effective method for controlling the buoyant emissions of foundry molds. The data presented has shown that a strong correlation exists between increasing air curtain slot exit velocity and increasing air curtain capture efficiencies. Capture efficiencies ranged from 63% to 105% at air curtain slot velocities of 1,653 to 2,662 ft/min, with increasing slot velocities delivering higher efficiencies. This data indicates that, with properly designed and operated equipment, industrial fugitive emission sources of fine particles can be economically controlled while allowing full equipment and personnel access to the emission source area. During virtually all pilot plant tests, foundry personnel were involved in operations in, around, or through the air curtain containment stream. Fugitive particle emissions were in many cases conveyed to the particle control device without appreciable losses. The air curtain transport system has been found to be a cost-effective solution to fugitive emission control with many benefits over expensive, cumbersome, and less effective methods such as hooding at the source or total building enclosure and evacuation, including lower capitol costs, greater process flexibility, and reduced personnel exposure to fine particle emissions.

The particle control filter unit portion of the pilot plant proved to be an effective unit, using High Efficiency Particulate Air (HEPA) filters and suction fans. Filter efficiency tests indicated that for particles between 0.1 µmA and 0.4 µmA in diameter, penetration was less than 1%, meaning that the efficiency of collection was greater than 99%. Source characterization determined that the mean particle size of typical mold emissions were in the range of 0.2 µmA to 0.4 µmA in diameter. Filter efficiency tests for particles larger than 0.5 µmA diameter did not yield conclusive results, however from the smaller particle size range information alone it can be concluded that the series 95 HEPA filters were an efficient means of collecting the fugitive particle emissions conveyed to the filter bank by the air curtain transport system.

The pilot plant unit installed at the demonstration site foundry, which consisted of an air curtain transport system and a HEPA type filter bank with suction fans, constituted an efficient, economical and versatile system for the control and entrapment of buoyant fugitive particle emissions from foundry molds. The overall capture and containment efficiency of the pilot plant when operating in the appropriate slot velocity range, can be expected to be between 90 and 99% when considered as a package. It is highly probable that the type of system quantified here will find widespread utility in many other industrial applications related to fugitive particle emission control.

SECTION 7
RECOMMENDATIONS

It is recommended that to expand upon the general utility of the information gathered in this project of air curtain control for fugitive particle emissions, certain further areas of application be investigated. In order to be used as an industrial system for general application, the effects of parameters such as crosswind control, scaling factors as a function of emission size, set-up parameters, and applicability of related system uses should be studied.

Crosswinds are important when the emission source is either outdoors, or in a large internal space. When air currents in the vicinity of the emission source are of large enough energy level to deflect the air curtain wedge being generated, the use of deflection screens is indicated. This can be accomplished with solid partitions, but would be more efficient if vertical air curtains were deployed as side deflection systems. This would allow for continual and unimpeded access to the emission area, yet relationships must be developed between crosswind energy levels and air curtain strength requirements to have simplified general application.

Scaling factors are also of importance. The utility of being able to reference a single information source in order to determine exactly which arrangement of air curtain size, orientation, strength, and filter parameters would be best suited for any particular application would be beneficial. It would also be useful to have a comprehensive guide of parameters and their implications with which to optimize any arrangement of equipment which was installed.

The applicability of this air curtain capture system and its associated particle collection unit for use in other emission source controls should be investigated. The possibilities for a variety of other related applications are enhanced by the versatility and utility of the basic nature of the system, and should prove to be of general value.

SECTION 8
QUALITY ASSURANCE

INTRODUCTION

The purpose of this Quality Control Evaluation Report is to substantiate and document the quality of the data taken during this research project, as well as to indicate the quality control activities performed during the tasks involved. This report provides sufficient data to enable a user of this information to determine the accuracy, completeness and precision of the results presented. It will also provide insights into limitations that may apply to the techniques used or the presented data.

OBJECTIVES

The major measurements for this study are the particle mass rate from the source and at the filter inlet and outlet. The quality assurance objective of the program is to assure that sampling is done correctly. The precision and completeness objectives are 15% and 90%, respectively. The sampling accuracy is not determinable because the source emission rate is not known and there is no calibration standard.

AIR CURRENT CAPTURE EFFICIENCY TESTS

Air curtain capture efficiency tests were conducted using a heated tracer gas (SF_6) to follow and mimic the behavior of the buoyant mold plume. Much of the applicability of this method relies on the assumption that the mold emissions (because of their small size) behave in a manner similar to a gas. In general, this is a good assumption, which has been supported by the source characterization studies that were performed, indicating that the mold emissions were indeed predominantly composed of small particles. A small level of non-conformity should, however, be expected between the behavior of the gas and the particles, which could lead to slight discrepancies in test results. The use of SF_6 as a tracer gas has been demonstrated in similar studies, which indicate its utility, including Baxter (1983), Bruffy (1983) and Deuble (1978).

For generation and injection of the tracer gas, there are only limited areas of uncertainty. The bottled gas (SF_6) itself is delivered at a carefully controlled factory calibrated concentration at ± 1% accuracy. Injection of the SF_6 tracer is controlled through a two stage pressure regulator and a calibrated rotometer with an expected accuracy of better than ± 2%. Rotometer readings were taken repeatedly during the testing and adjusted to the appropriate values. The 2% accuracy of the rotameter and the 1% accuracy of the mixture certification combine to yield a SF_6 injection accuracy of about 3%.

Tracer gas injection temperature was monitored and controlled at the same level as the median plume temperature in order to closely follow the buoyant plume. Inaccuracies here would parallel the general assumption of suitability of the tracer gas to mimic the plume. Dispersion of the tracer gas into the plume was uniform because it was done through four points distributed across the face of the mold surface (one in the center of each quadrant) with the exit velocity of the gas matching the median plume rise velocity.

Accuracy considerations involved in the air curtain itself center on the determination of the air exit velocity of the unit. This was measured using a hot wire anemometer which was recalibrated at regular intervals. Measurements were taken at twelve points across the outlet face of the air curtain and averaged in order to determine a representative value. Accuracies should be consistent with those encountered through standard use of hot wire anemometer probes (± 4%). Conversion of the exit velocity to a volumetric flow rate is based on work previously done by Yung et al (1981) with limitations as described therein.

The method used to determine concentration of tracer gas in the collection system has a number of areas of uncertainty. These include pitot tube velocity measurements, grab sample collection, sample transportation, and sample analysis. Velocity measurements taken with the pitot tube are subject to both the standard errors associated with the uses of a pitot tube as well as human error in positioning the pickup point at the appropriate location in the sample matrix. Position and attitude guides were used to minimize these problems, but they can not be excluded completely. In the area of the grab sampling matrix, sample collection method was a factor. Collection order was choosen randomly, and sample syringes where flushed twice before the final sample was captured, yet possible fluctuations in velocity or duct swirl could lead to misrepresentation since not all samples where taken simultaneously. After each test series, the gas grab samples were transported to and stored temporarily in the laboratory until they could be analyzed.

The normal transportation and storage interval previous to analysis of the gas samples was two to four hours. During sample analysis itself on the electron capture gas chromatagraph unit, accuracy was ensured through the use of both a two point calibration scheme and multiple daily calibrations. Random back checks were also performed through the use of replicates and duplicates to enhance reliability and to help spot any problems. It is estimated the gas chromatograph analysis of the SF_6 content of the samples is accurate to within 3%.

To evaluate the expected accuracy of the Air Curtain Capture Efficiency, the measured quantities contained in the capture efficiency equation need to be considered. The measured quantities in the numerators are concentration, area, and velocity. In the denominator the measured quantity is SF_6 injection volumetric flow rate. Here is a summary of the accuracies of these parameters:

Parameter	Method of Measurement	Accuracy
Concentration	S-Cubed Envirometer	3%
Area	Tape Measure with 1/16" Divisions	0.5%
Velocity	Thermal Anemometer	4%
SF_6 Injection	Rotameter & Gas Mixture Certification	3%

Then:

$$\text{Max. additive accuracy error} = \frac{1.03\ (1.005)\ (1.04)}{0.97} - 1 = +11\%$$

$$\text{Max. subtractive accuracy error} = 1 - \frac{0.97\ (0.995)\ (0.96)}{1.03} = -10\%$$

Thus, the expected accuracy of the Air Curtain Capture Efficiency is +11%, -10%.

In order to gain an overall measure of accuracy in the sampling of the SF_6 duct concentrations in relationship to the expected accuracy, a calibration was executed on the overall system from gas injection to capture to analysis. To perform this calibration, tests were performed in which sulfur hexafluoride was injected directly into the filter unit, and the air curtain was not operated. The SF_6 was injected into the system from three holes in a tube that was placed inside the collector unit at a point where good mixing was assured. During these tests, velocities were measured and samples were collected at the outlet duct in the manner previously described. Background samples were collected at the collection unit inlet and in the outlet duct, both before and after the injection of SF_6.

Six calibration determination tests were performed. Problems related to tracer gas recirculation (high SF_6 background concentrations) or equipment breakdown (velocity measurement device) occurred in three of those tests. The results of the three reliable calibration determination tests are summarized in Table 11. The mean value of the calibration efficiency is 97.97%. The confidence interval for a confidence level of 90% is in the range of from 79.33 to 116.61%.

TABLE 11. CALIBRATION DETERMINATION TESTS

Run No.	Filter Surface Velocity (cm/s)	(ft/min)	$\frac{\text{Measured } SF_6}{\text{Injected } SF_6}$
25-01	4.64	9.14	94.0
26-01	4.25	8.36	93.5
26-02	3.84	7.56	106.4

This confidence range of ± 18.6% describes the relative error in the air curtain capture efficiency measurements. In the work by Bruffy et al, similar types of measurements were shown to be subject to an ± 18% error limit on tracer recovery of SF_6 when used with air curtain systems. This ± 18% actual error is greater than the expected theoretical error of +11%-10% and is assumably derived from errors related to nonuniformity of sampling due to velocity fluctuations and duct swirling. It can be assumed that a ± 18% error should be assigned to all data associated with the air curtain capture efficiency. This ± 18% figure also will provide an explanation for tracer recovery figures which are in excess of 100%.

FILTER COLLECTION EFFICIENCY TESTS

Filter collection efficiency tests were performed to determine how effective the selected filter media was at collecting mold emissions captured by the air curtain containment system. Collection efficiency was determined by quantifying both upstream and downstream particle concentrations, and then determining the particulate penetration levels.

Testing for filter collection efficiency was done with a dedicated portable hood and blower in order to avoid the dilution of the particulate plume which occurs during air curtain testing. This equipment arrangement used the same filter media and was necessary to ensure high levels of particulate concentrations in the air stream to allow for measurement. In order to assure that representative data was gathered, filter collection tests were done on molds with the same configuration as the other air curtain tests, and all tests were performed in as similar a manner of timing and execution as possible. The type and method of sampling duplicated the air curtain capture tests, and therefore should produce representative information within the accuracy limits which will be discussed.

Two methods were used to determine particle concentrations. These were: cascade impactors for particles greater than 0.5 μmA, and an Electrical Aerosol Size Analyzer for particles less than 0.5 μmA.

For the larger particles, cascade impactors were calibrated, operated and analyzed with strict adherence to both the exhaustive guidelines spelled out in the Quality Assurance Project Plan, as well as the various EPA guidelines for cascade impactors as listed in the QAPP. Two University of Washington Mark III cascade impactors were used. Before sampling for the project began, each cascade impactor was given a "quick check" by stage to determine if any deviations of greater than 5% from the previous calibrations were apparent. No deviations beyond this 5% limit were observed. Two sample trains were used during the sampling program. Before the sampling, trains were used, they were serviced and the dry gas meter and the orifice meter were checked for 5 points on the existing calibration curve with a factory calibrated and certified dry gas meter. The quick check differed less than 2% from the existing calibration. Though operations and analysis were performed with great precision, the results of these cascade impactor tests are in question. This question is raised in part, because of an artifact of the analysis: weight gains by impactor substrate were often only on the order of 0.1 or 0.2 mg, while the predicted accuracy of the weight measurement system is only ± 0.1 mg. This shows that much of the gathered data for Cascade Impactors has no statistical meaning, and should be disregarded. It further shows that the particle size distribution contained almost no particles in the larger size fractions measured. This artifact affects all filter collection efficiency data for particles greater than 0.5 μmA, but does not affect in any way data for smaller particles since a different method was used.

For particles of less than 0.5 μmA size, an Electrical Aerosol Size Analyser (ESA) was used. The direct accuracy of the ESA system is ± 5% but can be affected by some environmental conditions. The ESA had just been returned from a complete factory refurbishment as well as recalibration, and therefore should not be expected to deviate beyond its accuracy limits. For a complete discussion of the factors involved, a standard guide for ESA use should be consulted. Filter system outlet concentrations were fed directly to the ESA unit for concentration measurements, and therefore should be assumed to be within the same accuracy as the ESA system. Filter system inlet concentrations were of too high a concentration for direct measurement with the ESA system. In order to bring these concentrations down to a level acceptable to the ESA--a precision dilution system was used. This system consisted of two calibrated orifice flow meters and an extensive mixing chamber. Since mixing was complete, the accuracy of the dilution system centers on the orifice flow meters which are rated at ± 2% each. This accuracy level should be used to adjust the ESA overall accuracy for inlet concentrations, and this final accuracy should be used to describe the overall results of collection efficiency as determined by ESA Analysis, which can be estimated to be on the order of ± 7%

Internal Quality Control Checks

Internal quality control checks were used to ensure valid data collection. The guidelines for the operational checks, control limits, and corrective actions are summarized in Table 12. These checks were considered continually by the persons performing the sampling and sample processing. In addition, the Project Engineer made weekly observations of the methods used by the technicians. When any deviation was observed, corrective instructions were given. No significant problems were discovered during the internal checks.

TABLE 12. INTERNAL QC CHECK

Operation Check	Control Limits	Planned Corrective Action
1. Calibrations	1. Calibration	1.
a. Dry Gas Meter	a. ± 1%	a,b, & c. Recalibrate
b. Rotameter	b. ± 1%	d. Replace Thermocouple
c. Orifice Meter	c. ± 1%	e. Reshape, Sharpen, & Recalibrate
d. Thermocouple	d. ± 1°C of Reference Thermometer	
e. Nozzles	e. 3 Measurements Within	
f. Field Barometer	f. ± 0.1 in. Hg of Mercury-in-Glass Barometer	f. Use National Weather Service Information
g. Electronic Balance	g. Adjust to ± 0.1 g. mg of standard weight	Return to manufacturer for service
h. Field Balance	h. ± 0.5 g of standard weight	h. Adjust or return to manufacturer
2. Filters	2. Properly Desiccated, Labeled, No Tears, Weighted, Installed	2. Replace
3. Impactor Substrates	3. Properly Desiccated & Labeled Flat and No Grease Underneath	3. Replace
4. Sample Containers	4. Clean Polyethylene Bottle Properly Labeled	4. Replace
5. Acetone	5. Reagent Grade 0.001% Glass Bottle	5. Replace

Performance Audits

The sampling and data analysis procedures (including computations) were audited by A.P.T.'s Quality Assurance Manager. For each test area, the methods were observed for compliance with the Project Assurance Plan. No deviations from the plan were found during these audits.

An audit was performed by S-cubed during the first day of the projects sampling effort. Certain "shakedown" deficiencies were noted at that time and these included updating the QAPP to include the SF_6 tracer studies and aerosol particle size measurements, initiating sampling as soon as possible after the mold is poured, randomizing the sample point sequence to reduce systematic errors, attempting to keep the sites cargo doors closed at all times, and maintaining a complete log of the experimental conditions. Suggestions were made to improve documentation and procedures in various areas. These suggestions were implemented immediately, with the mentioned deficiencies corrected in very short order.

CONCLUSIONS

The general objective for accuracy in this project was ± 15%. The goal was exceeded slightly in the Air Curtain Capture Efficiency Tests as indicated by the ± 18% accuracy. It is apparent from other references, however, that the ± 18% figure is an appropriate accuracy level for this particular arrangement. In the filter collection efficiency tests, the 7% accuracy determination is within the 15% goal.

REFERENCES

1. Baxter, Robert A., "Quantifying Fugitive Emissions from Mining and Material Handling Operations Using Gas Trace Techniques", presented at the 76th meeting of the Air Pollution Control Association, (June, 1983).

2. Bruffy, C., P. Clarke, T. Clark and M. Phillips, "Evaluation of an Air Curtain Hooding System for a Primary Cooper Converter--Volume I", EPA 600/2-84-042a, (NTIS PB84-160514), 1984.

3. Deuble, J. L., "Atmospheric Tracer Gas Technology, Techniques and Applications", Technical Bulletin 79-5, Systems, Science and Software, La Jolla, CA.

4. Yung, S., J. Curran, and S. Calvert. Spray Charging and Trapping Scrubber for Fugitive Particle Emission Control. EPA-600/7-81-125, (NTIS PB82-115304), U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, 1981.

APPENDIX A
AIR CURTAIN CAPTURE EFFICIENCY TEST DATA

DATA SHEET FOR MOLD TESTING

Test Number: 22-01

Test Date: 3-26-84

Mold Information:
Metal Type: CN7M-SS

Metal Weight: 415 **lb.**

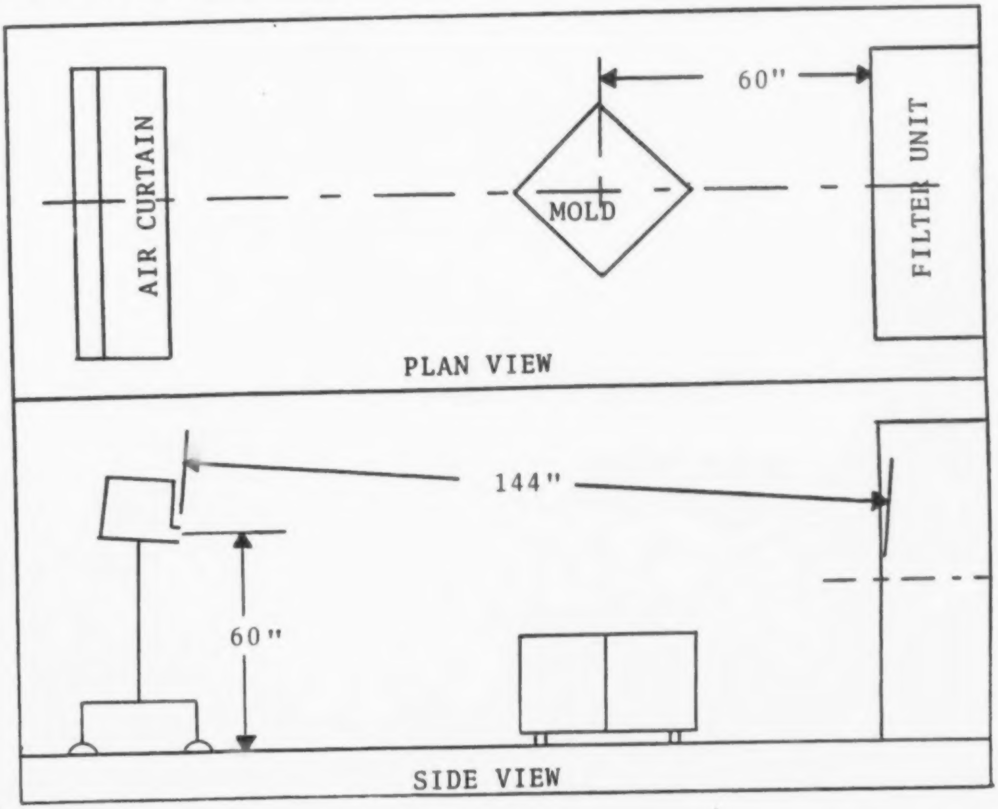
Sand Type: AIR SET/RESIN CAT.

Mold Dimensions (LxWxH) 30X30X23 **in.**

Ambient Conditions:
Temperature 71 **°F**

Relative Humidity: 80 **%**

Barametric Pressure 29.90 **in. Hg.**


AIR CURTAIN
60"
MOLD
FILTER UNIT
PLAN VIEW
144"
60"
SIDE VIEW

Dataredc.frm
Project 79

DATA REDUCTION: AIR CURTAIN VELOCITIES & VOLUMETRIC FLOW

Test Number: 22-01

Test Date: 3-26-84

Reduction Date: 9-16-84

Kurz Meter Readings @ Air Curtain Slot (FPM):

3700	5000	1350	2000	4800	3400	3800	3800	1350	2200	3400	2900

(orientation: looking at A.C. slot)

True Slot Velocities (FPM)

From Calibration Dated 3-28-84 with $Y=0.875X-87.5$

3150	4288	1094	1663	4113	2888	3238	3238	1094	1838	2888	2450

Left Half Avg. Velocity= 2866 fpm Right Half Avg. Velocity= 2458 fpm

Overall Avg. Slot Velocity= 2662 fpm = "A"

Distance between slot & filter unit inlet= 144 in = "B"

Air Curtain Volumetric Flow Rate at Filter unit inlet

$$= Q_x = (0.66)(0.919\ \text{ft}^2)(\text{"A" fpm})\left(\frac{\text{"B" in}}{2.3\ \text{in}}\right)^{0.5} =$$

= 12,798 CFM

Dataredc.frm
Project 79

```
DATA REDUCTION FOR AIR CURTAIN CAPTURE EFFICIENCY TESTS

Test number      79-22-01
Test date        03-26-84
Reduction date   08-13-84

INPUT

Barometric  pressure                                         29.9 in Hg
Ambient temperature at filter unit inlet                       86 F
Saturated vapor pressure at ambient temp (from table)       1.253 in Hq
Relative humidity at filter unit inlet                         80 %
Duct temperature                                               79 F
Duct gauge pressure                                            .4 in WC
Sulfur hexafluoride concentration of injection gas          101.6 ppm
Tracer gas injection rate at calibration
      conditions (from calibration curve)                   .0092 ACFM
Rotameter outlet temperature                                   80 F
Rotameter outlet gauge pressure                                 0 in WC

Duct pitot tube readings (in. W.C.), looking upstream
                                    0        0        0        0        0
                                    0        0        0        0        0
                                    0        0        0        0        0
                                    0        0        0        0        0

Duct sulfur hexafluoride concentrations (ppt), looking upstream
                                   60       97       78       61       74
                                   68       95       90       68       50
                                   64       77      109       73       33
                                   54       63       72       88       50

OUTPUT

Absolute duct pressure                             29.93 in. Hg
Water vapor volume / air and water volume          .0335
Molecular weight, wet basis                        28.63 lb./lb.-mole
Duct velocity =  4066.93 fpm * (h/in. W.C.)1/2

Duct velocities (fpm), looking  upstream
                                 3240     3060     2469     2370     1050
                                 3150     2840     2584     2180     1050
                                 2975     2620     2561     2010     1400
                                 2620     2450     2261     1840     1400

Total flow rate  13410.0 ACFM

Sulfur Hexafluoride volumetric flow rates at 29.92 in Hg & 68 F
                         9.17e-7  SCFM   Injected
                         9.62e-7  SCFM   Measured at duct

Capture efficiency             105.0 %
```

DATA SHEET FOR MOLD TESTING

Test Number: 27-01

Test Date: 8-6-84

Mold Information:
Metal Type: CN7M

Metal Weight: 360 **lb.**

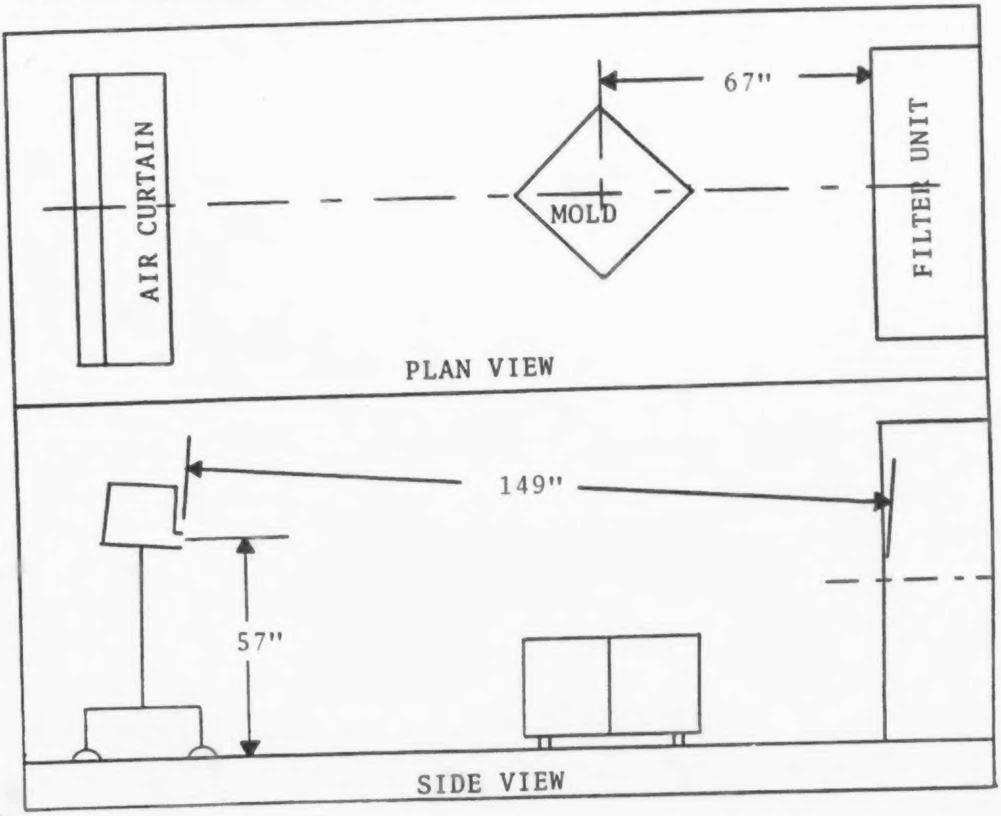
Sand Type: AIR-SET

Mold Dimensions (LxWxH) 32X32X23 **in.**

Ambient Conditions:
Temperature 79 **°F**

Relative Humidity: 75 **%**

Barametric Pressure 29.89 **in. Hg.**


67"
AIR CURTAIN
MOLD
FILTER UNIT
PLAN VIEW
149"
57"
SIDE VIEW

Dataredc.frm
Project 79

DATA REDUCTION: AIR CURTAIN VELOCITIES & VOLUMETRIC FLOW

Test Number: 27-01

Test Date: 8-6-84

Reduction Date: 9-16-84

Kurz Meter Readings @ Air Curtain Slot (FPM):

2800	3800	1150	1650	2600	2750	3200	2600	1100	1550	2700	2300

(orientation: looking at A.C. slot)

True Slot Velocities (FPM)

From Calibration Dated 8-8-84 with Y=0.840X+157.94

2510	2752	1124	1544	2342	2468	2846	2342	2082	1460	2426	2090

Left Half Avg. Velocity= 2125 fpm Right Half Avg. Velocity= 2041 fpm

Overall Avg. Slot Velocity= 2083 fpm = "A"

Distance between slot & filter unit inlet= 149 in = "B"

Air Curtain Volumetric
Flow Rate at Filter
unit inlet

$$= Q_x = (0.66)(0.919\ \text{ft}^2)(\text{"A" fpm})\left(\frac{\text{"B" in}}{2.3\ \text{in}}\right)^{.5} =$$

= 10,173 CFM

Dataredc.frm
Project 79

```
DATA REDUCTION FOR AIR CURTAIN CAPTURE EFFICIENCY TESTS

Test number       79-27-A1
Test date         08-06-84
Reduction date    08-08-84

INPUT

Barometric  pressure                                        29.89 in Hg
Ambient temperature at filter unit inlet                       79 F
Saturated vapor pressure at ambient temp (from table)        .999 in Hg
Relative humidity at filter unit inlet                         75 %
Duct temperature                                               80 F
Duct gauge pressure                                          1.35 in WC
Sulfur hexafluoride concentration of injection gas          101.6 ppm
Tracer gas injection rate at calibration
     conditions (from calibration curve)                     .012 ACFM
Rotameter outlet temperature                                   82 F
Rotameter outlet gauge pressure                                 0 in WC

Duct pitot tube readings (in. W.C.), looking upstream
                             .415    .315   .2825   .2675     .09
                             .445    .295     .31    .275      .1
                             .415   .2425   .3425    .255   .1325
                             .395    .255    .305     .24    .165

Duct sulfur hexafluoride concentrations (ppt), looking upstream
                             22.2    28.4    70.9   139.8   183.9
                             19.1    36.1      78   132.2   136.8
                              9.7    37.6    75.5    97.9   181.6
                             19.1    26.9    49.8   105.4   172.4

OUTPUT

Absolute duct pressure                              29.99 in. Hg
Water vapor volume / air and water volume           .0251
Molecular weight, wet basis                         28.72 lb./lb.-mole
Duct velocity =   4060.05 fpm * (h/in. W.C.)1/2

Duct velocities (fpm), looking  upstream
                            2616.   2279.   2158.   2100.   1218.
                            2708.   2205.   2261.   2129.   1284.
                            2616.   1999.   2376.   2050.   1478.
                            2552.   2050.   2242.   1989.   1649.

Total flow rate   12197.4 ACFM

Sulfur Hexafluoride volumetric flow rates at 29.92 in Hg & 68 F
                      1.20e-6  SCFM   Injected
                      8.59e-7  SCFM   Measured at duct

Capture efficiency             71.62 %
```

DATA SHEET FOR MOLD TESTING

Test Number: 27-02

Test Date: 8-9-84

Mold Information:

Metal Type: VALVE BRONZE

Metal Weight: 195 **lb.**

Sand Type: AIR-SET

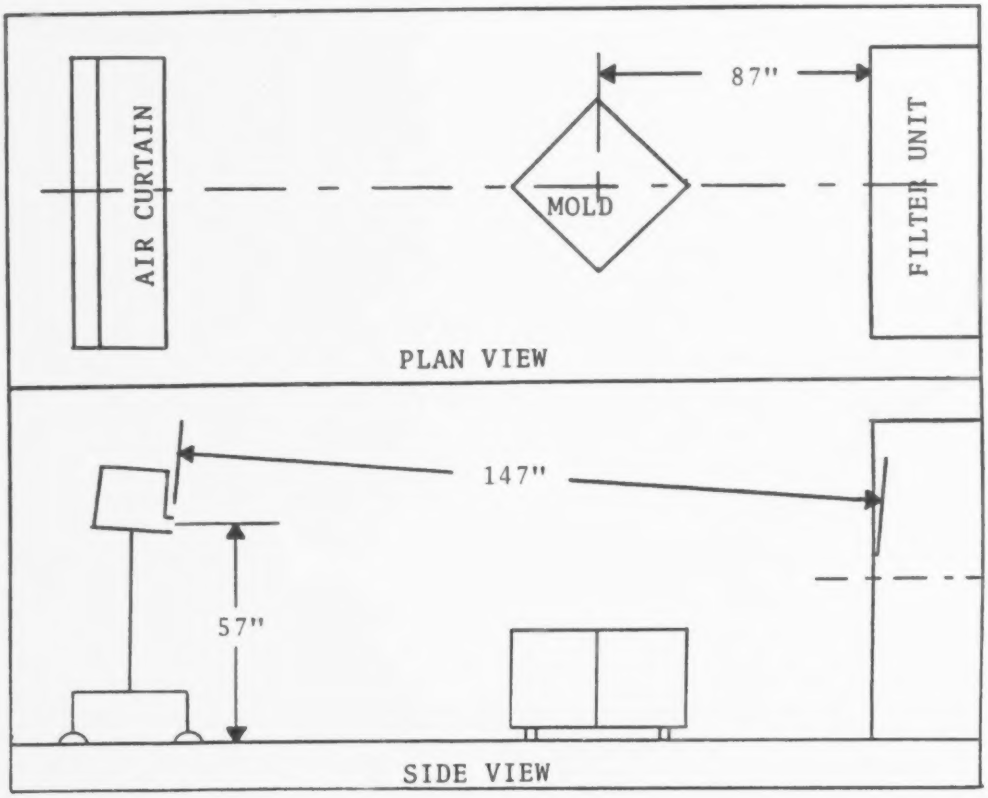
Mold Dimensions (LxWxH) 30X30X24 **in.**

Ambient Conditions:

Temperature 74 **°F**

Relative Humidity: 85 **%**

Barametric Pressure 29.86 **in. Hg.**


AIR CURTAIN
87"
MOLD
FILTER UNIT
PLAN VIEW
147"
57"
SIDE VIEW

Dataredc.frm
Project 79

DATA REDUCTION: AIR CURTAIN VELOCITIES & VOLUMETRIC FLOW

Test Number: 27-02

Test Date: 8-9-84

Reduction Date: 6-16-84

Kurz Meter Readings @ Air Curtain Slot (FPM):

3000	3600	1200	1750	3550	2800	3300	3300	950	1550	2900	2800

(orientation: looking at A.C. slot)

True Slot Velocities (FPM)

From Calibration Dated 8-8-84 with $Y=0.840X+157.94$

2678	3182	1166	1628	3140	2594	2930	2930	956	1460	2594	2510

Left Half Avg. Velocity= 2398 fpm Right Half Avg. Velocity= 2230 fpm

Overall Avg. Slot Velocity= 2314 fpm = "A"

Distance between slot & filter unit inlet= 147 in = "B"

Air Curtain Volumetric
Flow Rate at Filter
unit inlet

$$= Q_x = (0.66)(0.919\ \text{ft}^2)(\text{"A" fpm})\left(\frac{\text{"B" in}}{2.3\ \text{in}}\right)^{.5} =$$

= 11,221 CFM

Dataredc.frm
Project 79

```
DATA REDUCTION FOR AIR CURTAIN CAPTURE EFFICIENCY TESTS

Test number      79-27-02
Test date        08-09-84
Reduction date   08-10-84

INPUT

Barometric  pressure                                      29.86 in Hq
Ambient temperature at filter unit inlet                     74 F
Saturated vapor pressure at ambient temp (from table)      .846 in Hg
Relative humidity at filter unit inlet                       85 %
Duct temperature                                             76 F
Duct gauge pressure                                         1.5 in WC
Sulfur hexafluoride concentration of injection gas        101.6 ppm
Tracer gas injection rate at calibration
      conditions (from calibration curve)                  .012 ACFM
Rotameter outlet temperature                                 73 F
Rotameter outlet gauge pressure                             .04 in WC

Duct pitot tube readings (in. W.C.), looking upstream
                            .505    .345    .295    .33    .085
                            .495    .3      .32     .325   .0975
                            .45     .25     .3375   .28    .1375
                            .42     .265    .315    .255   .17

Duct sulfur hexafluoride concentrations (ppt), looking upstream
                            75.6   105.7   122.1    63.5   36.1
                            95     110.2   132.5    76.7   25.3
                            64.4   101.2    89.2    86.2   41.3
                            75.6   114.6   113.1   132.8   49

OUTPUT

Absolute duct pressure                             29.97 in. Hg
Water vapor volume / air and water volume          .0241
Molecular weight, wet basis                        28.74 lb./lb.-mole
Duct velocity =  4045.49 fpm * (h/in. W.C.)1/2

Duct velocities (fpm), looking  upstream
                         2875.  2376.  2197.  2324.  1179.
                         2846.  2216.  2288.  2306.  1263.
                         2714.  2023.  2350.  2141.  1500.
                         2622.  2083.  2271.  2043.  1668.

Total flow rate  12583.0 ACFM

Sulfur Hexafluoride volumetric flow rates at 29.92 in Hq & 68 F:
                  1.21e-6  SCFM   Injected
                  1.10e-6  SCFM   Measured at duct

Capture efficiency          90.97 %
```

DATA SHEET FOR MOLD TESTING

Test Number: 28-02

Test Date: 9-11-84

Mold Information:

Metal Type: CARBON STEEL

Metal Weight: 200 lb.

Sand Type: AIR-SET

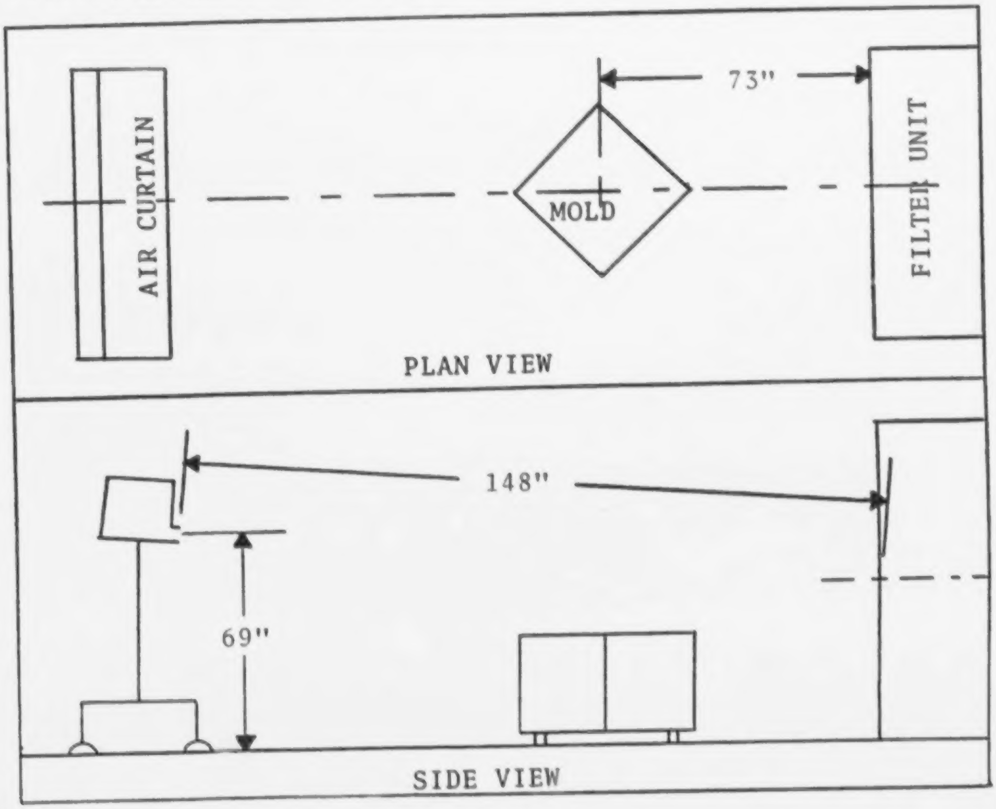
Mold Dimensions (LxWxH) 30X30X32 in.

Ambient Conditions:

Temperature 78 °F

Relative Humidity: 85 %

Barametric Pressure 29.75 in. Hg.


73"
AIR CURTAIN
MOLD
FILTER UNIT
PLAN VIEW
148"
69"
SIDE VIEW

Dataredc.frm
Project 79

DATA REDUCTION: AIR CURTAIN VELOCITIES & VOLUMETRIC FLOW

Test Number: 28-02

Test Date: 9-11-84

Reduction Date: 9-16-84

Kurz Meter Readings @ Air Curtain Slot (FPM):

2500	2500	1100	1650	2600	2400	2600	1800	1000	1400	2300	2600

(orientation: looking at A.C. slot)

True Slot Velocities (FPM)

From Calibration Dated 8-8-84 with Y=0.840X+157.94

2258	2258	1082	1544	2342	2174	2342	1670	988	1334	2090	2342

Left Half Avg. Velocity= 1943 fpm Right Half Avg. Velocity= 1796 fpm

Overall Avg. Slot Velocity= 1869.5 fpm = "A"

Distance between slot & filter unit inlet= 148 in = "B"

Air Curtain Volumetric
Flow Rate at Filter
unit inlet

$$= Q_X=(0.66)(0.919\ \text{ft}^2)(\text{"A" fpm})\left(\frac{\text{"B" in}}{2.3\ \text{in}}\right)^{.5}=$$

= 9,096 CFM

Dataredc.frm
Project 79

```
DATA REDUCTION FOR AIR CURTAIN CAPTURE EFFICIENCY TESTS

Test number      79-28-02
Test date        09-11-84
Reduction date   09-12-84

INPUT

Barometric  pressure                                    29.75 in Hg
Ambient temperature at filter unit inlet                   77 F
Saturated vapor pressure at ambient temp (from table)    .935 in Hg
Relative humidity at filter unit inlet                     85 %
Duct temperature                                           81 F
Duct gauge pressure                                       1.2 in WC
Sulfur hexafluoride concentration of injection gas      101.6 ppm
Tracer gas injection rate at calibration
     conditions (from calibration curve)                 .012 ACFM
Rotameter outlet temperature                               77 F
Rotameter outlet gauge pressure                          .065 in WC

Duct pitot tube readings (in. W.C.), looking upstream
                             .33    .27    .22    .25    .07
                             .36    .25    .27    .25    .09
                             .37    .22    .29    .23    .1
                             .34    .23    .27    .23    .14

Duct sulfur hexafluoride concentrations (ppt), looking upstream
                           59.24  171.7  134.5  86.36  31.73
                           37.61  154.6  143.4  97.28  23.54
                           48.29  121.3  148.4  143.8  49.57
                           75.26  69.13  135.6  142.3  25.18

OUTPUT

Absolute duct pressure                             29.84  in. Hg
Water vapor volume / air and water volume          .0267
Molecular weight, wet basis                        28.71  lb./lb.-mole
Duct velocity =  4075.37 fpm * (h/in. W.C.)1/2

Duct velocities (fpm), looking  upstream
                           2341.  2118.  1912.  2038.  1078.
                           2445.  2038.  2118.  2038.  1223.
                           2479.  1912.  2195.  1954.  1289.
                           2376.  1954.  2118.  1954.  1525.

Total flow rate  11367.3 ACFM

Sulfur Hexafluoride volumetric flow rates at 29.92 in Hg & 68 F:
            1.20e-6  SCFM   Injected
            1.09e-6  SCFM   Measured at duct

Capture efficiency         90.49 %
```

DATA SHEET FOR MOLD TESTING

Test Number: 28-03

Test Date: 9-13-84

Mold Information:

Metal Type: TIN BRONZE

Metal Weight: 100 **lb.**

Sand Type: AIR-SET

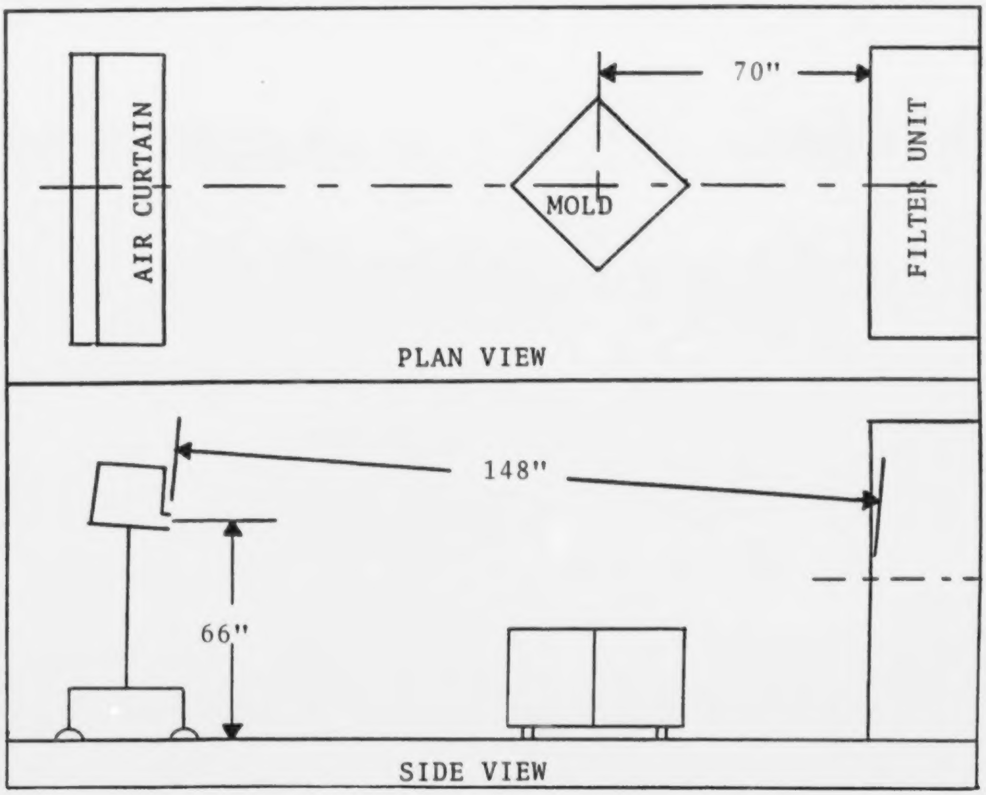
Mold Dimensions (LxWxH) 24X24X20 **in.**

Ambient Conditions:

Temperature 81 **°F**

Relative Humidity: 84 **%**

Barametric Pressure 29.86 **in. Hg.**


70"
AIR CURTAIN
MOLD
FILTER UNIT
PLAN VIEW
148"
66"
SIDE VIEW

Dataredc.frm
Project 79

DATA REDUCTION: AIR CURTAIN VELOCITIES & VOLUMETRIC FLOW

Test Number: 28-03

Test Date: 9-13-84

Reduction Date: 9-16-84

Kurz Meter Readings @ Air Curtain Slot (FPM):

2000	1950	850	1300	2100	2300	1950	1650	950	1800	2100	2400

(orientation: looking at A.C. slot)

True Slot Velocities (FPM)

From Calibration Dated 8-8-84 with Y=0.840X+157.94

1838	1796	872	1250	1922	2090	1796	1544	956	1670	1922	2174

Left Half Avg. Velocity= 1628 fpm Right Half Avg. Velocity= 1677 fpm

Overall Avg. Slot Velocity= 1652.5 fpm = "A"

Distance between slot & filter unit inlet= 148 in = "B"

Air Curtain Volumetric Flow Rate at Filter unit inlet

$$= Q_x = (0.66)(0.919 \text{ ft}^2)(\text{"A" fpm})\left(\frac{\text{"B" in}}{2.3 \text{ in}}\right)^{.5} =$$

= 8,040 CFM

Dataredc.frm
Project 79

```
DATA REDUCTION FOR AIR CURTAIN CAPTURE EFFICIENCY TESTS

Test number      79-28-03
Test date        09-13-84
Reduction date   09-14-84

INPUT

Barometric  pressure                                   29.86 in Hg
Ambient temperature at filter unit inlet                  82 F
Saturated vapor pressure at ambient temp (from table)  1.102 in Hg
Relative humidity at filter unit inlet                    84 %
Duct temperature                                          83 F
Duct gauge pressure                                      .95 in WC
Sulfur hexafluoride concentration of injection gas     101.6 ppm
Tracer gas injection rate at calibration
     conditions (from calibration curve)                .012 ACFM
Rotameter outlet temperature                              82 F
Rotameter outlet gauge pressure                          .07 in WC

Duct pitot tube readings (in. W.C.), looking upstream
                             .25    .27    .16    .17    .09
                             .28    .19    .19    .19    .09
                             .26    .16    .22    .21    .1
                             .24    .18    .23    .19    .14

Duct sulfur hexafluoride concentrations (ppt), looking upstream
                           14.94   56.3  105.7  122.2  157.0
                            8.41   65.4  103.3  150.4  192.4
                            3.42  26.08  65.71  127.2  142.5
                           21.29  16.55  60.72  87.55  134.9

OUTPUT

Absolute duct pressure                           29.93  in. Hg
Water vapor volume / air and water volume        .0310
Molecular weight, wet basis                      28.66  lb./lb.-mole
Duct velocity =  4080.00 fpm * (h/in. W.C.)^1/2

Duct velocities (fpm), looking  upstream
                           2040.  2120.  1632.  1682.  1224.
                           2159.  1778.  1778.  1778.  1224.
                           2080.  1632.  1914.  1870.  1290.
                           1999.  1731.  1957.  1778.  1527.

Total flow rate  10230.9 ACFM

Sulfur Hexafluoride volumetric flow rates at 29.92 in Hg & 68 F:
                 1.20e-6  SCFM   Injected
                 7.61e-7  SCFM   Measured at duct

Capture efficiency          63.41 %
```

DATA SHEET FOR MOLD TESTING

Test Number: 28-04

Test Date: 9-17-84

Mold Information:
Metal Type: CF8M

Metal Weight: 290 lb.

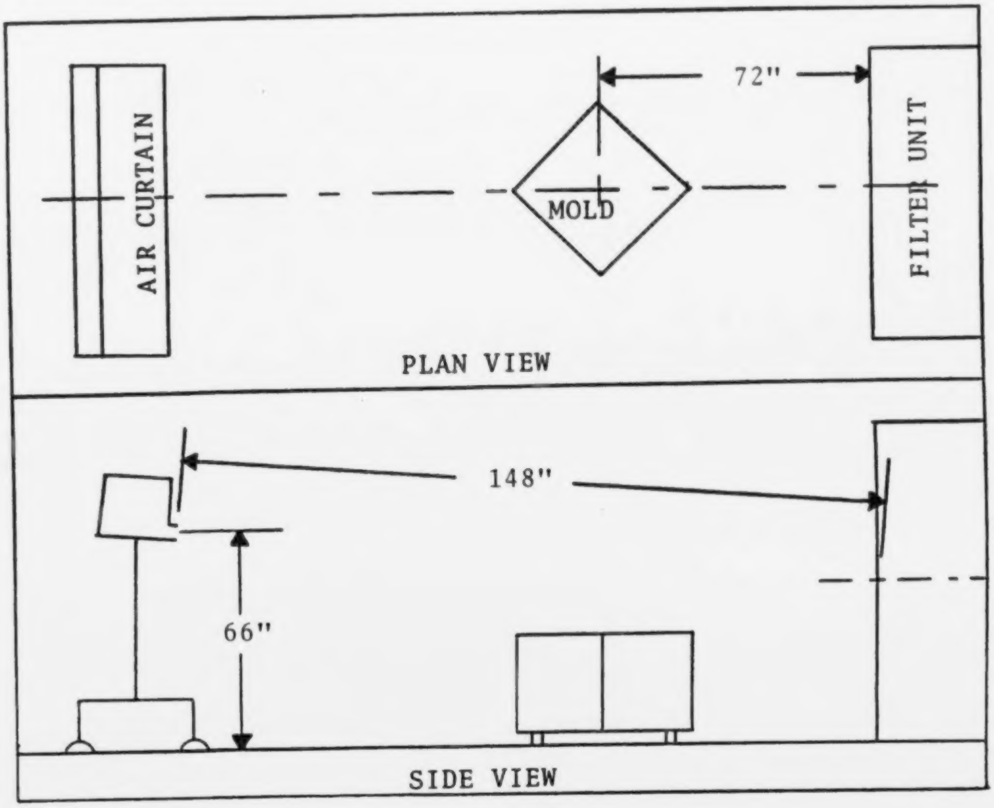
Sand Type: AIR-SET

Mold Dimensions (LxWxH) 36X36X24 in.

Ambient Conditions:
Temperature 84 °F

Relative Humidity: 72 %

Barametric Pressure 29.89 in. Hg.


72"
AIR CURTAIN
MOLD
FILTER UNIT
PLAN VIEW
148"
66"
SIDE VIEW

Dataredc.frm
Project 79

DATA REDUCTION: AIR CURTAIN VELOCITIES & VOLUMETRIC FLOW

Test Number: 28-04

Test Date: 9-17-84

Reduction Date: 9-18-84

Kurz Meter Readings @ Air Curtain Slot (FPM):

2400	2900	1200	1400	3200	3000	3000	2900	1050	1200	2800	2600

(orientation: looking at A.C. slot)

True Slot Velocities (FPM)

From Calibration Dated 8-8-84 with Y=0.840X+157.94

2174	2594	1166	1334	2846	2678	2678	2594	1040	1166	2510	2342

Left Half Avg. Velocity= 2132 fpm Right Half Avg. Velocity= 2055 fpm

Overall Avg. Slot Velocity= 2093 fpm = "A"

Distance between slot & filter unit inlet= 148 in = "B"

Air Curtain Volumetric
Flow Rate at Filter
unit inlet

$$= Q_x = (0.66)(0.919\ \text{ft}^2)(\text{"A" fpm})\left(\frac{\text{"B" in}}{2.3\ \text{in}}\right)^{.5} =$$

= 10,168 CFM

Dataredc.frm
Project 79

```
DATA REDUCTION FOR AIR CURTAIN CAPTURE EFFICIENCY TESTS

Test number     79-28-A4
Test date       09-17-84
Reduction date  09-18-84

INPUT

Barometric  pressure                                     29.89 in Hg
Ambient temperature at filter unit inlet                  84.5 F
Saturated vapor pressure at ambient temp (from table)    1.195 in Hg
Relative humidity at filter unit inlet                      72 %
Duct temperature                                            90 F
Duct gauge pressure                                        1.1 in WC
Sulfur hexafluoride concentration of injection gas       101.6 ppm
Tracer gas injection rate at calibration
     conditions (from calibration curve)                  .012 ACFM
Rotameter outlet temperature                                86 F
Rotameter outlet gauge pressure                            .08 in WC

Duct pitot tube readings (in. W.C.), looking upstream
                              .31    .26    .19    .19    .06
                              .33    .24    .24    .22    .07
                              .34    .21    .25    .19    .09
                              .31    .23    .25     .2    .13

Duct sulfur hexafluoride concentrations (ppt), looking upstream
                            41.75  118.9  99.79  123.3  93.39
                            38.48  79.31  112.4  120.5    138
                            10.35  74.56  90.36  155.4  104.5
                            38.48  36.27   87.2  115.8  122.1

OUTPUT

Absolute duct pressure                          29.97 in. Hg
Water vapor volume / air and water volume       .0288
Molecular weight, wet basis                     28.68 lb./lb.-mole
Duct velocity =  4101.67 fpm * (h/in. W.C.)1/2

Duct velocities (fpm), looking upstream
                            2284.  2091.  1788.  1788.  1005.
                            2356.  2009.  2009.  1924.  1085.
                            2392.  1880.  2051.  1788.  1231.
                            2284.  1967.  2051.  1834.  1479.

Total flow rate  10841.7 ACFM

Sulfur Hexafluoride volumetric flow rates at 29.92 in Hg & 68 F:
                 1.20e-6  SCFM   Injected
                 8.89e-7  SCFM   Measured at duct

Capture efficiency           74.39 %
```

```
DATA REDUCTION FOR AIR CURTAIN CAPTURE EFFICIENCY TESTS

Test number      79-29-04
Test date        10-31-84
Reduction date   11-07-84

INPUT

Barometric  pressure                                       29.99 in Hg
Ambient temperature at filter unit inlet                      70 F
Saturated vapor pressure at ambient temp (from table)      .739 in Hg
Relative humidity at filter unit inlet                        73 %
Duct temperature                                              76 F
Duct gauge pressure                                           .7 in WC
Sulfur hexafluoride concentration of injection gas         101.6 ppm
Tracer gas injection rate at calibration
     conditions (from calibration curve)                   .012 ACFM
Rotameter outlet temperature                                  71 F
Rotameter outlet gauge pressure                              .06 in WC

Duct pitot tube readings (in. W.C.), looking upstream
                   .13      .13     .14     .12     .13      .1
                   .14      .12     .16     .13     .16     .09
                   .15       .1     .17     .13     .21      .1
                   .16      .11     .16     .15     .24     .12

Duct sulfur hexafluoride concentrations (ppt), looking upstream
                 116.5       35    95.3   119.3   115.4      70
                    45     28.9    78.7    78.7   100.3      94
                  22.7      155      55    86.6    88.6    78.7
                  20.6     22.6      47   108.8    76.7    95.3

OUTPUT

Absolute duct pressure                           30.04 in. Hg
Water vapor volume / air and water volume        .0180
Molecular weight, wet basis                      28.80 lb./lb.-mole
Duct velocity =  4035.99 fpm * (h/in. W.C.)1/2

Duct velocities (fpm), looking  upstream
              1455.20     1455.  1510.  1398.  1455.  1276.
              1510.13     1398.  1614.  1455.  1614.  1211.
              1563.13     1276.  1664.  1455.  1850.  1276.
              1614.40     1339.  1614.  1563.  1977.  1398.

Total flow rate  10448.8 ACFM

Sulfur Hexafluoride volumetric flow rates at 29.92 in Hg & 68 F:
              1.21e-6  SCFM   Injected
              7.83e-7  SCFM   Measured at duct

Capture efficiency         64.48 %
```

DATA SHEET FOR MOLD TESTING

Test Number: 29-01

Test Date: 10-22-84

Mold Information:

Metal Type: B-STEEL

Metal Weight: 180 **lb.**

Sand Type: AIR-SET

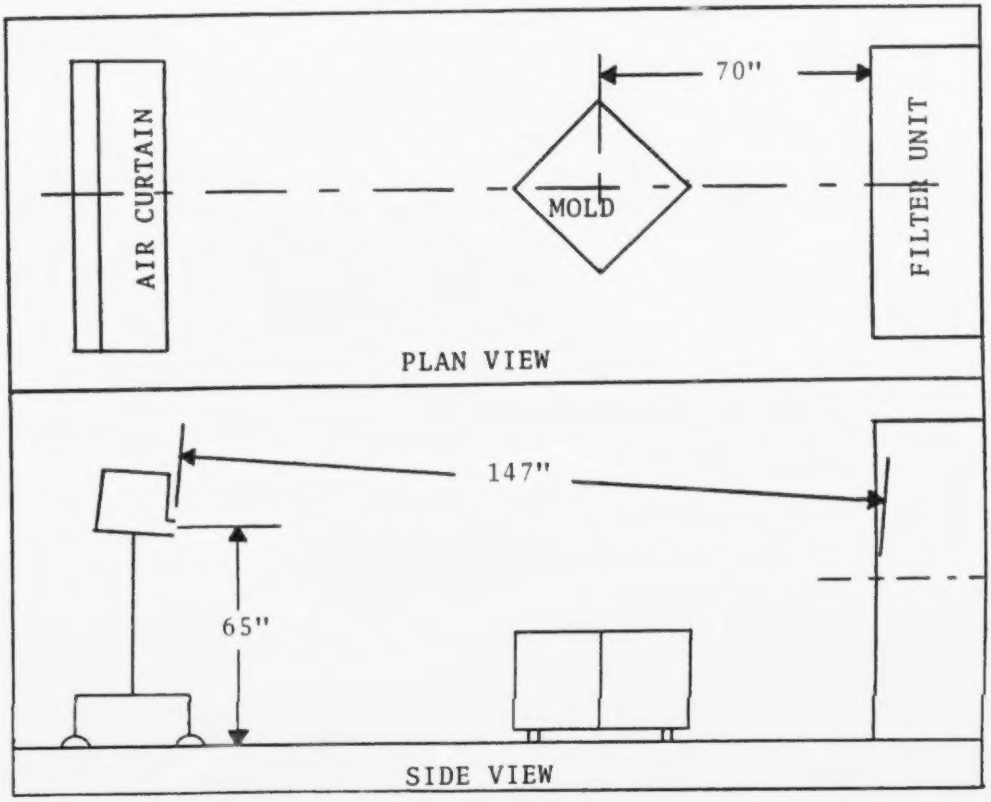
Mold Dimensions (LxWxH) 40X24X16 **in.**

Ambient Conditions:

Temperature 71 **°F**

Relative Humidity: 69 **%**

Barametric Pressure 30.01 **in. Hg.**


70"
AIR CURTAIN
MOLD
FILTER UNIT
PLAN VIEW
147"
65"
SIDE VIEW

Dataredc.frm
Project 79

DATA REDUCTION: AIR CURTAIN VELOCITIES & VOLUMETRIC FLOW

Test Number: 29-01

Test Date: 10-22-84

Reduction Date: 10-24-84

Kurz Meter Readings @ Air Curtain Slot (FPM):

3200	3800	1300	1900	3600	3300	3900	3700	1150	1500	3500	3100

(orientation: looking at A.C. slot)

True Slot Velocities (FPM)

From Calibration Dated 8-8-84 with Y=0.840X+157.94

2845	3350	1250	1754	3182	2930	3434	3266	1124	1418	3098	2762

Left Half Avg. Velocity= 2552 fpm Right Half Avg. Velocity= 2517 fpm

Overall Avg. Slot Velocity= 2534 fpm = "A"

Distance between slot & filter unit inlet= 147 in = "B"

Air Curtain Volumetric
Flow Rate at Filter
unit inlet

$$= Q_x = (0.66)(0.919\ \text{ft}^2)(\text{"A" fpm})\left(\frac{\text{"B" in}}{2.3\ \text{in}}\right)^{.5} =$$

= 12,287 CFM

Dataredc.frm
Project 79

```
DATA REDUCTION FOR AIR CURTAIN CAPTURE EFFICIENCY TESTS

Test number      79-29-01
Test date        10-22-84
Reduction date   10-24-84

INPUT

Barometric  pressure                                      30.01 in Hg
Ambient temperature at filter unit inlet                   71.5 F
Saturated vapor pressure at ambient temp (from table)      .778 in Hg
Relative humidity at filter unit inlet                       69 %
Duct temperature                                             76 F
Duct gauge pressure                                        1.25 in WC
Sulfur hexafluoride concentration of injection gas        101.6 ppm
Tracer gas injection rate at calibration
     conditions (from calibration curve)                   .012 ACFM
Rotameter outlet temperature                               71.5 F
Rotameter outlet gauge pressure                             .05 in WC

Duct pitot tube readings (in. W.C.), looking upstream
                       .33      .25      .28      .18      .21      .07
                       .37      .26      .3       .19      .22      .08
                       .37      .24      .26      .21      .26      .09
                       .35      .26      .22      .25      .25      .12

Duct sulfur hexafluoride concentrations (ppt), looking upstream
                     84.07    88.18    69.72    63.47    55.19    65.54
                    114.75    110.7    79.96    79.96    73.79    86.12
                     149.3    75.85    82.02    94.32    84.07    57.26
                       129    77.91    55.19    75.85    108.6    77.91

OUTPUT

Absolute duct pressure                               30.10 in. Hg
Water vapor volume / air and water volume            .0179
Molecular weight, wet basis                          28.80 lb./lb.-mole
Duct velocity =  4031.86 fpm * (h/in. W.C.)1/2

Duct velocities (fpm), looking  upstream
                   2316.13    2016.    2133.    1711.    1848.    1067.
                   2452.49    2056.    2208.    1757.    1891.    1140.
                   2452.49    1975.    2056.    1848.    2056.    1210.
                   2385.28    2056.    1891.    2016.    2016.    1397.

Total flow rate  13358.7 ACFM

Sulfur Hexafluoride volumetric flow rates at 29.92 in Hg & 68 F:
                   1.21e-6  SCFM   Injected
                   1.16e-6  SCFM   Measured at duct

Capture efficiency          95.36 %
```

DATA SHEET FOR MOLD TESTING

Test Number: 29-03

Test Date: 10-30-84

Mold Information:

Metal Type: VALVE BRONZE

Metal Weight: 180 **lb.**

Sand Type: AIR-SET

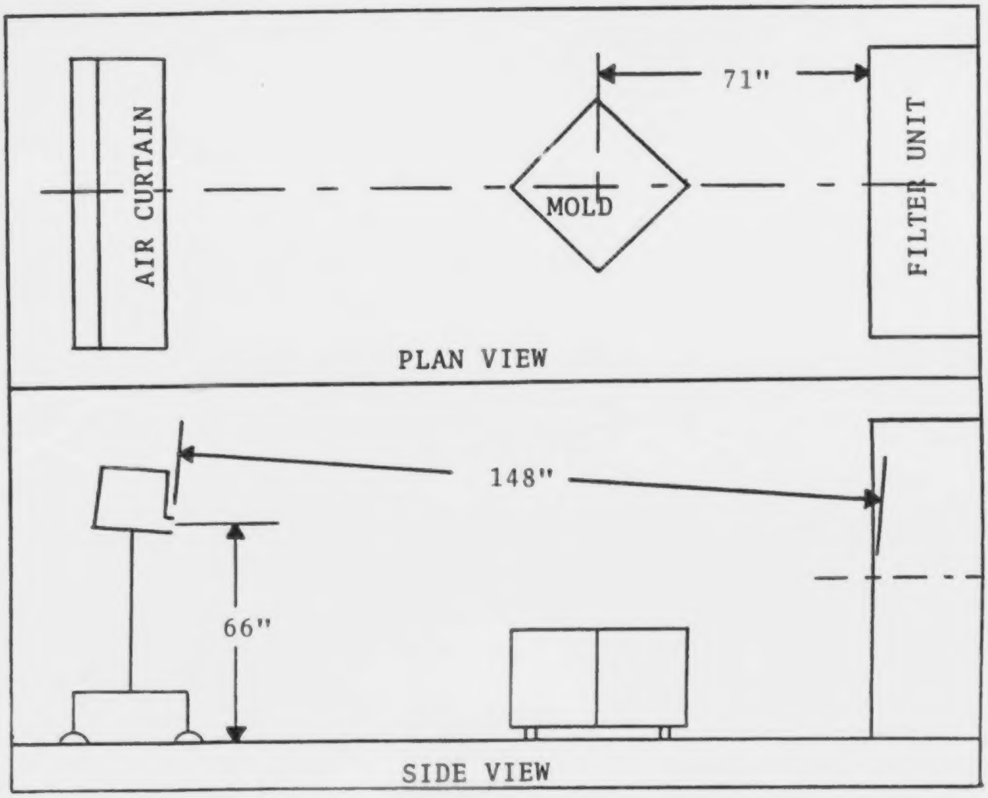
Mold Dimensions (LxWxH) 25X25X17 **in.**

Ambient Conditions:

Temperature 69 **°F**

Relative Humidity: 83 **%**

Barametric Pressure 29.97 **in. Hg.**


71"
AIR CURTAIN
MOLD
FILTER UNIT
PLAN VIEW
148"
66"
SIDE VIEW

Dataredc.frm
Project 79

DATA REDUCTION: AIR CURTAIN VELOCITIES & VOLUMETRIC FLOW

Test Number: 29-03

Test Date: 10-30-84

Reduction Date: 11-2-84

Kurz Meter Readings @ Air Curtain Slot (FPM):

2700	2400	1350	1800	2800	2900	3200	2100	1400	1800	2700	2800

(orientation: looking at A.C. slot)

True Slot Velocities (FPM)

From Calibration Dated 8-8-84 with Y=0.840X+157.94

2426	2174	1292	1670	2510	2594	2846	1922	1334	1670	2426	2510

Left Half Avg. Velocity= 2111 fpm Right Half Avg. Velocity= 2118 fpm

Overall Avg. Slot Velocity= 2115 fpm = "A"

Distance between slot & filter unit inlet= 148 in = "B"

Air Curtain Volumetric
Flow Rate at Filter
unit inlet

$$= Q_x = (0.66)(0.919\ \text{ft}^2)(\text{"A" fpm})\left(\frac{\text{"B" in}}{2.3\ \text{in}}\right)^{.5} =$$

= 10,291 CFM

```
DATA REDUCTION FOR AIR CURTAIN CAPTURE EFFICIENCY TESTS

Test number      79-29-03
Test date        10-30-84
Reduction date   11-02-84

INPUT

Barometric  pressure                                          29.97 in Hg
Ambient temperature at filter unit inlet                         69 F
Saturated vapor pressure at ambient temp (from table)          .714 in Hg
Relative humidity at filter unit inlet                           83 %
Duct temperature                                                 75 F
Duct gauge pressure                                             .81 in WC
Sulfur hexafluoride concentration of injection gas            101.6 ppm
Tracer gas injection rate at calibration
      conditions (from calibration curve)                      .012 ACFM
Rotameter outlet temperature                                     72 F
Rotameter outlet gauge pressure                                 .04 in WC

Duct pitot tube readings (in. W.C.), looking upstream
                       .2      .19      .2      .12      .15      .09
                      .22      .18     .21      .12      .18      .08
                      .22      .16     .21      .13      .22       .1
                      .22      .15     .17      .17      .23      .12

Duct sulfur hexafluoride concentrations (ppt), looking upstream
                     83.2     77.1    48.4       67     18.8       65
                    131.6     68.9    80.9     80.9     59.1       65
                    105.4     83.2    86.8    108.4     49.1     47.1
                    109.5     87.2    78.9     57.1       67    110.4

OUTPUT

Absolute duct pressure                               30.03 in. Hg
Water vapor volume / air and water volume            .0198
Molecular weight, wet basis                          28.78 lb./lb.-mole
Duct velocity =  4034.40 fpm * (h/in. W.C.)1/2

Duct velocities (fpm), looking  upstream
                 1804.24    1759.  1804.  1398.  1563.  1210.
                 1892.30    1712.  1849.  1398.  1712.  1141.
                 1892.30    1614.  1849.  1455.  1892.  1276.
                 1892.30    1563.  1663.  1663.  1935.  1398.

Total flow rate  11433.8 ACFM

Sulfur Hexafluoride volumetric flow rates at 29.92 in Hg & 68 F:
                 1.21e-6  SCFM   Injected
                 8.75e-7  SCFM   Measured at duct

Capture efficiency          72.13 %
```

DATA SHEET FOR MOLD TESTING

Test Number: 29-04

Test Date: 10-31-84

Mold Information:
Metal Type: CF8M

Metal Weight: 200 lb.

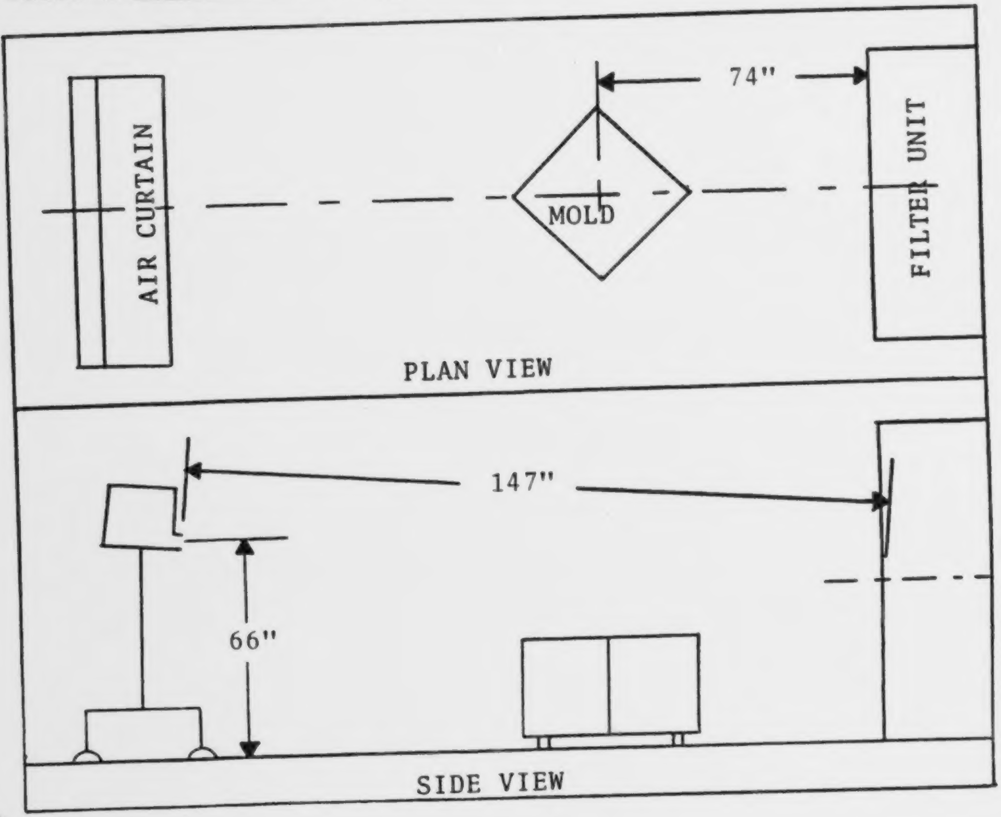
Sand Type: AIR-SET

Mold Dimensions (LxWxH) 40X40X25 in.

Ambient Conditions:
Temperature 70 °F

Relative Humidity: 73 %

Barametric Pressure 29.99 in. Hg.


74"
AIR CURTAIN
MOLD
FILTER UNIT
PLAN VIEW
147"
66"
SIDE VIEW

Dataredc.frm
Project 79

DATA REDUCTION: AIR CURTAIN VELOCITIES & VOLUMETRIC FLOW

Test Number: 29-04

Test Date: 10-31-84

Reduction Date: 11-6-84

Kurz Meter Readings @ Air Curtain Slot (FPM):

2200	2100	1200	950	2300	2500	2400	2100	1200	1400	2600	2800

(orientation: looking at A.C. slot)

True Slot Velocities (FPM)

From Calibration Dated 8-8-84 with Y=0.840X+157.94

2006	1922	1166	956	2090	2258	2174	1922	1166	1334	2342	2510

Left Half Avg. Velocity= 1733 fpm Right Half Avg. Velocity= 1908 fpm

Overall Avg. Slot Velocity= 1821 fpm = "A"

Distance between slot & filter unit inlet= 148 in = "B"

Air Curtain Volumetric Flow Rate at Filter unit inlet $= Q_x = (0.66)(0.919\ \text{ft}^2)(\text{"A" fpm})\left(\frac{\text{"B" in}}{2.3\ \text{in}}\right)^{.5} =$

= 8,860 CFM

Dataredc.frm
Project 79

DATA SHEET FOR MOLD TESTING

Test Number: 30-01

Test Date: 11-6-84

Mold Information:
Metal Type: BRONZE

Metal Weight: 500 **lb.**

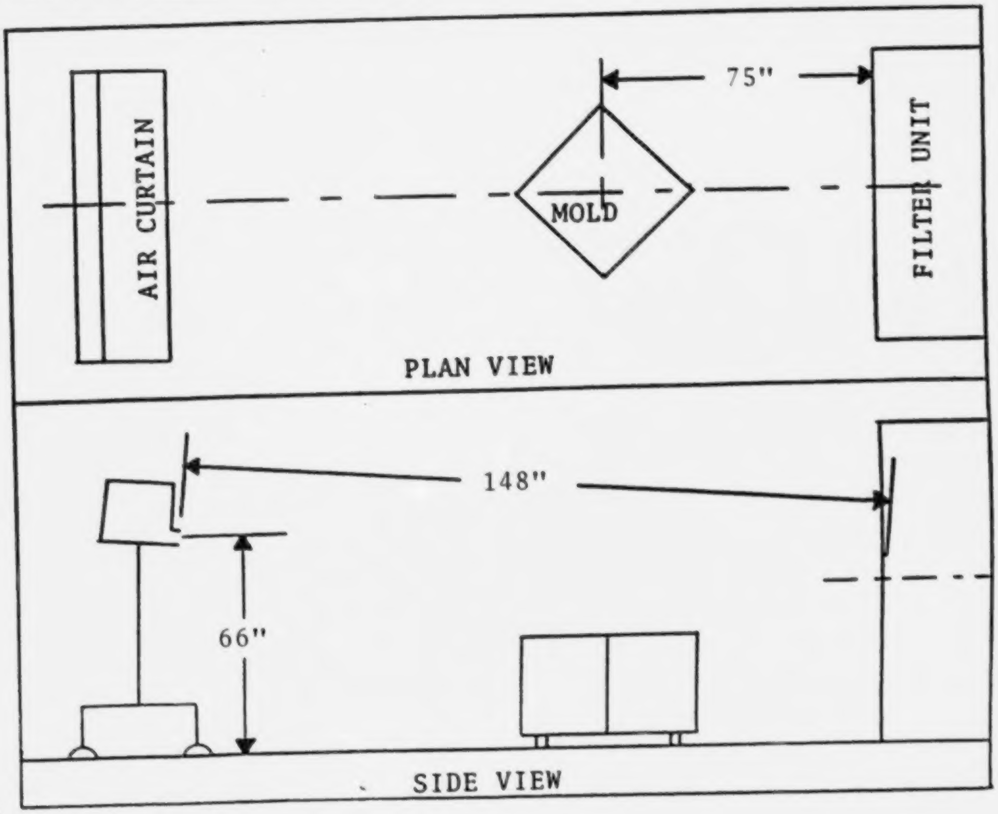
Sand Type: AIR-SET

Mold Dimensions (LxWxH) 38X38X24 **in.**

Ambient Conditions:
Temperature 69 **°F**

Relative Humidity: 76 **%**

Barametric Pressure 30.01 **in. Hg.**


75"
AIR CURTAIN
MOLD
FILTER UNIT
PLAN VIEW
148"
66"
SIDE VIEW

Dataredc.frm
Project 79

DATA REDUCTION: AIR CURTAIN VELOCITIES & VOLUMETRIC FLOW

Test Number: 30-01

Test Date: 11-6-84

Reduction Date: 11-9-84

Kurz Meter Readings @ Air Curtain Slot (FPM):

2400	2600	1300	1700	2700	3000	3400	2600	1500	1700	3000	2900

(orientation: looking at A.C. slot)

True Slot Velocities (FPM)

From Calibration Dated 8-8-84 with Y=0.840X+157.94

2594	2342	1250	1586	2426	2678	3014	2342	1418	1586	2678	2594

Left Half Avg. Velocity= 2146 fpm Right Half Avg. Velocity= 2272 fpm

Overall Avg. Slot Velocity= 2209 fpm = "A"

Distance between slot & filter unit inlet= 148 in = "B"

Air Curtain Volumetric
Flow Rate at Filter
unit inlet

$$= Q_x = (0.66)(0.919\ \text{ft}^2)(\text{"A" fpm})\left(\frac{\text{"B" in}}{2.3\ \text{in}}\right)^{.5} =$$

= 10,748 CFM

```
DATA REDUCTION FOR AIR CURTAIN CAPTURE EFFICIENCY TESTS

Test number      79-30-01
Test date        11-06-84
Reduction date   11-09-84

INPUT

Barometric  pressure                                       30.01 in Hg
Ambient temperature at filter unit inlet                      69 F
Saturated vapor pressure at ambient temp (from table)       .714 in Hg
Relative humidity at filter unit inlet                        76 %
Duct temperature                                              73 F
Duct gauge pressure                                         1.15 in WC
Sulfur hexafluoride concentration of injection gas         101.6 ppm
Tracer gas injection rate at calibration
     conditions (from calibration curve)                    .012 ACFM
Rotameter outlet temperature                               68.5 F
Rotameter outlet gauge pressure                              .09 in WC

Duct pitot tube readings (in. W.C.), looking upstream
                         .31      .24      .27      .19      .17      .07
                         .34      .24      .28      .18      .23      .08
                         .36      .24      .25       .2      .24       .1
                         .35      .25      .21      .24      .23      .11

Duct sulfur hexafluoride concentrations (ppt), looking upstream
                        77.5    124.5     91.6    134.2       72     78.1
                        31.2       76     70.1    143.8    136.1    105.4
                        46.5     77.9     79.9    118.7    112.9    113.2
                        54.5     60.3     52.4     85.7      109    120.9

OUTPUT

Absolute duct pressure                          30.09 in. Hg
Water vapor volume / air and water volume       .0181
Molecular weight, wet basis                     28.80 lb./lb.-mole
Duct velocity =  4021.20 fpm * (h/in. W.C.)1/2

Duct velocities (fpm), looking  upstream
                    2238.91    1970.   2089.   1753.   1658.   1064.
                    2344.74    1970.   2128.   1706.   1928.   1137.
                    2412.72    1970.   2011.   1798.   1970.   1272.
                    2378.97    2011.   1843.   1970.   1928.   1334.

Total flow rate   13048.1 ACFM

Sulfur Hexafluoride volumetric flow rates at 29.92 in Hg & 68 F:
                    1.22e-6   SCFM    Injected
                    1.14e-6   SCFM    Measured at duct

Capture efficiency          93.75 %
```

DATA SHEET FOR MOLD TESTING

Test Number: 30-02

Test Date: 11-15-84

Mold Information:
Metal Type: CF8M

Metal Weight: 660 **lb.**

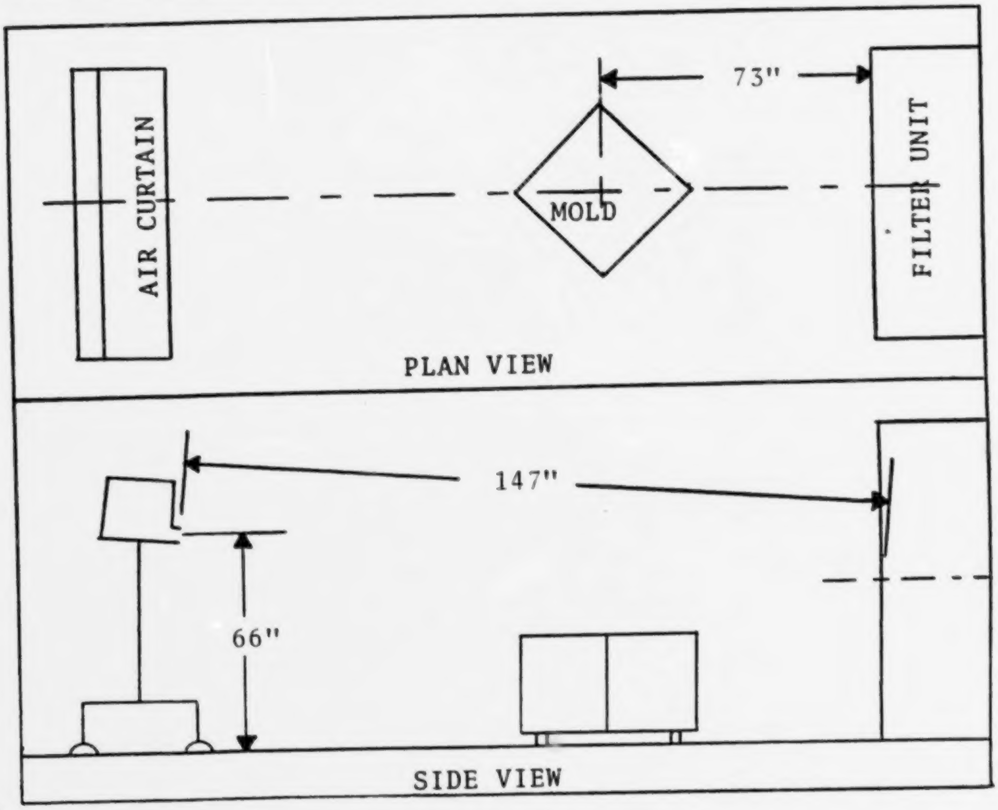
Sand Type: AIR-SET

Mold Dimensions (LxWxH) 38X38X24 **in.**

Ambient Conditions:
Temperature 68 **°F**

Relative Humidity: 75 **%**

Barametric Pressure 30.17 **in. Hg.**


73"
AIR CURTAIN
MOLD
FILTER UNIT
PLAN VIEW
147"
66"
SIDE VIEW

Dataredc.frm
Project 79

DATA REDUCTION: AIR CURTAIN VELOCITIES & VOLUMETRIC FLOW

Test Number: 30-02

Test Date: 11-15-84

Reduction Date: 11-20-84

Kurz Meter Readings @ Air Curtain Slot (FPM):

3100	3500	1400	2000	3500	3200	3500	3600	1400	1500	2400	3200

(orientation: looking at A.C. slot)

True Slot Velocities (FPM)

From Calibration Dated 8-8-84 with Y=0.840X+157.94

2762	3098	1334	1838	3098	2846	3098	3182	1334	1418	2594	2846

Left Half Avg. Velocity= 2496 fpm Right Half Avg. Velocity= 2412 fpm

Overall Avg. Slot Velocity= 2454 fpm = "A"

Distance between slot & filter unit inlet= 147 in = "B"

Air Curtain Volumetric Flow Rate at Filter unit inlet $= Q_x = (0.66)(0.919\ \text{ft}^2)(\text{"A" fpm})\left(\frac{\text{"B" in}}{2.3\ \text{in}}\right)^{.5} =$

= 11,899 CFM

Dataredc.frm
Project 79

```
DATA REDUCTION FOR AIR CURTAIN CAPTURE EFFICIENCY TESTS

Test number      79-30-02
Test date        11-15-84
Reduction date   11-20-84

INPUT

Barometric  pressure                                        30.17 in Hg
Ambient temperature at filter unit inlet                       68 F
Saturated vapor pressure at ambient temp (from table)         .69 in Hg
Relative humidity at filter unit inlet                         75 %
Duct temperature                                               73 F
Duct gauge pressure                                            75 in WC
Sulfur hexafluoride concentration of injection gas          101.6 ppm
Tracer gas injection rate at calibration
     conditions (from calibration curve)                     .012 ACFM
Rotameter outlet temperature                                   70 F
Rotameter outlet gauge pressure                               .09 in WC

Duct pitot tube readings (in. W.C.), looking upstream
                          .37      .25      .3      .23      .28      .11
                          .42      .26     .29      .24      .29      .12
                          .42      .29     .26      .25      .29      .13
                          .36      .32     .25      .28      .27      .15

Duct sulfur hexafluoride  concentrations (ppt), looking upstream
                       94.46    94.46   131.6   96.58    68.16   70.07
                       80.69    30.95   87.14   87.14    81.46   66.26
                       80.69    30.95   94.69   90.92    62.45   62.45
                       60.92    22.86   102.2   96.58    111.7   81.46

OUTPUT

Absolute duct pressure                              35.68 in. Hg
Water vapor volume / air and water volume           .0172
Molecular weight, wet basis                         28.81 lb./lb.-mole
Duct velocity =  3692.17 fpm * (h/in. W.C.)1/2

Duct velocities (fpm), looking  upstream
                    2245.86     1846.   2022.   1771.   1954.   1225.
                    2392.80     1883.   1988.   1809.   1988.   1279.
                    2392.80     1988.   1883.   1846.   1988.   1331.
                    2215.30     2089.   1846.   1954.   1919.   1430.

Total flow rate  13164.2 ACFM

Sulfur Hexafluoride volumetric flow rates at 29.92 in Hg & 68 F:
                    1.22e-6  SCFM   Injected
                    1.23e-6  SCFM   Measured at duct

Capture efficiency         100.6 %
```

APPENDIX B

FILTER EFFICIENCY TEST DATA

DATA SHEET FOR MOLD TESTING

Test Number: 31-01

Test Date: 12-11-84

Mold Information:
Metal Type: VALVE BRONZE

Metal Weight: 45 lb.

Sand Type: SYNTHETIC

Mold Dimensions (LxWxH) 24X24X21 in.

Ambient Conditions:
Temperature 66 °F

Relative Humidity: 89 %

Barametric Pressure 29.85 in. Hg.

Dataredc.frm
Project 79

```
*****     IMPACTOR DATA REDUCTION    *****

*****   INPUT DATA    *****

Date of test:       12/11/84
Time of test:       11:00 AM
Test location:      SIMA-FOUNDRY
Project number:     79
Inlet/Outlet:      INLET
Run number:         3101 - FILE NAME: T79R3101.IT
Run remarks:        FILTER EFFICIENCY TEST
Impactor I.D.                      UWD1
                     UNIVERSITY OF WASHINGTON IMPACTOR 'D'

Water vapor         1.00% (From  'KEYBOARD)
Carbon dioxide     0.00%    Carbon monoxide   0.00%
Oxygen            21.00%    Nitrogen         79.00%

Sample train I.D.:                 APT10LG
Gas meter volume                   21.036 cubic feet
Orifice DELTA P                     0.30 inches W.C.
Rotameter S.S. ball reading:       19.00
Stack pressure                     +0.00 inches W.C.
Barometric pressure                29.85 inches HG
Stack temperature                  74 degrees F
Meter temperature                  60 degrees F
Average Vacuum:                     4.00 inches HG
Impactor temperature               66 degrees F
Impactor DELTA P                    1.00 psi
Sample time                        31.00 minutes
Average velocity of gas          4,300.00 feet/minute
Nozzle diameter                     0.19 inches

     ***** RESULTS *****

Actual flow rate                   0.774 acfm
Satandard conditions               0.775 scfm
Percent isokinetic                95.82 %
Viscosity of gas stream            0.000179 g/cm-s

STAGE        C.WEIGHT        C.CONC       C.FRACT          AERO. DIA.
                   mg       mg/DNm^3                           umA
-----        --------       ------       -------         ----------
  1              1.90         2.82         1.000          20.51
  2              1.60         2.38         0.842           8.99
  3              1.00         1.49         0.526           3.48
  4              0.80         1.19         0.421           1.84
  5              0.70         1.04         0.368           1.10
  6              0.60         0.89         0.316           0.69
  7              0.40         0.59         0.211           0.41
 FILTER          0.30         0.45         0.158

Total mass concentration =      2.822 mg/DNm^3
```

```
    *****     IMPACTOR DATA REDUCTION     *****

    *****   INPUT DATA     *****

Date of test:        12/11/84
Time of test:        11:00 AM
Test location:       SIMA-FOUNDRY
Project number:      79
Inlet/Outlet:       OUTLET
Run number:          3101 - FILE NAME: T79R3101.OT
Run remarks:         FILTER EFFICIENCY TEST
Impactor I.D.                    UWC1
                      UNIVERSITY OF WASHINGTON IMPACTOR 'C'

Water vapor         1.00% (From  'KEYBOARD)
Carbon dioxide     0.00%    Carbon monoxide   0.00%
Oxygen            21.00%    Nitrogen         79.00%

Sample train I.D.:                 APT6HF
Gas meter volume                   71.146 cubic feet
Orifice DELTA P                     2.90 inches W.C.
Rotameter S.S. ball reading:       19.00
Stack pressure                     -1.00 inches W.C.
Barometric pressure                29.85 inches HG
Stack temperature                  74 degrees F
Meter temperature                  60 degrees F
Average Vacuum:                     8.00 inches HG
Impactor temperature               66 degrees F
  pactor DELTA P                    1.00 psi
Sample time                        31.00 minutes
Average velocity of gas         4,300.00 feet/minute
Nozzle diameter                     0.38 inches

      ***** RESULTS *****

Actual flow rate                   2.477 acfm
Satandard conditions               2.475 scfm
Percent isokinetic                76.25 %
Viscosity of gas stream            0.000179 g/cm-s

 STAGE        C.WEIGHT         C.CONC       C.FRACT          AERO. DIA.
                 mg          mg/DNm^3                           umA
 -----        --------         ------       -------          ----------
   1            0.80            0.37         1.000           11.46
   2            0.50            0.23         0.625            5.02
   3            0.50            0.23         0.625            1.93
   4            0.50            0.23         0.625            1.04
   5            0.10            0.05         0.125            0.64
  FILTER        0.00            0.00         0.000

Total mass concentration =      0.372 mg/DNm^3
```

```
             EFFICIENCY CALCULATIONS

        Project Number  79
        Run Number      3101

             * * * FINITE DIFFERENCE METHOD * * *

             Part. Dia.(umA)          Penetration (fraction)
                  0.60                        0.0002
                  0.70                        0.0048
                  0.80                        0.0883
                  0.90                        0.1932
                  1.00                        0.2847
                  2.00                        0.0097
                  4.00                        0.0000
                 10.00                        0.0001
```

DATA REDUCTION FOR ELECTRICAL AEROSOL SIZE ANALYZER

Test Number: 31-01

Test Date: 12-11-84

Reduction Date: 12-14-84

Filter Surface Velocity 7.5 ft/min

MEAN CUT DIAMETER (From Aerosol Size Analyzer) [μm]	PENETRATION (By Finite Difference Method) [Fraction]
0.0178	0.0005
0.0316	0.0032
0.0562	0.0018
0.100	0.0017
0.178	0.0021
0.316	0.0098

dataredc.frm
project 79

DATA SHEET FOR MOLD TESTING

Test Number: 31-02

Test Date: 12-12-84

Mold Information:

Metal Type: CF8M

Metal Weight: 200 **lb.**

Sand Type: SYNTHETIC

Mold Dimensions (LxWxH) 32X24X8 **in.**

Ambient Conditions:

Temperature 77 **°F**

Relative Humidity: 70 **%**

Barametric Pressure 29.89 **in. Hg.**

Dataredc.frm
Project 79

```
*****     IMPACTOR DATA REDUCTION    *****

*****   INPUT DATA    *****

ate of test:       12/12/84
me of test:        10:00 AM
Test location:     SIM
Project number:    79
Inlet/Outlet:     INLET
Run number:        3102 - FILE NAME: T79R3102.IT
Run remarks:       FILTER EFFICIENCY TEST
Impactor I.D.                   UWD1
                    UNIVERSITY OF WASHINGTON IMPACTOR 'D'

Water vapor        1.00% (From  'KEYBOARD)
Carbon dioxide     0.00%    Carbon monoxide   0.00%
Oxygen            21.00%    Nitrogen         79.00%

Sample train I.D.:               APT10LG
Gas meter volume                 20.601 cubic feet
Orifice DELTA P                   0.30 inches W.C.
Rotameter S.S. ball reading:     19.00
Stack pressure                   +0.00 inches W.C.
Barometric pressure              29.89 inches HG
Stack temperature               109 degrees F
Meter temperature                60 degrees F
Average Vacuum:                   4.00 inches HG
Impactor temperature             77 degrees F
Impactor DELTA P                  1.00 psi
Sample time                      32.00 minutes
  erage velocity of gas      3,150.00 feet/minute
Nozzle diameter                   0.19 inches

    ***** RESULTS *****

Actual flow rate                 0.742 acfm
Satandard conditions             0.728 scfm
Percent isokinetic             130.79 %
Viscosity of gas stream          0.000182 g/cm-s

 STAGE       C.WEIGHT       C.CONC      C.FRACT          AERO. DIA.
                   mg     mg/DNm^3                           umA
 -----       --------       ------      -------          ----------
   1             2.40         3.68        1.000          21.11
   2             1.90         2.91        0.792           9.25
   3             1.70         2.60        0.708           3.58
   4             1.30         1.99        0.542           1.89
   5             0.90         1.38        0.375           1.13
   6             0.40         0.61        0.167           0.71
   7             0.30         0.46        0.125           0.42
  FILTER         0.10         0.15        0.042

Total mass concentration =     3.675 mg/DNm^3
```

```
*****     IMPACTOR DATA REDUCTION    *****

*****   INPUT DATA    *****

Date of test:          12/12/84
Time of test:          10:00 AM
Test location:         SIMA-FOUNDRY
Project number:        79
Inlet/Outlet:         OUTLET
Run number:            3102 - FILE NAME: T79R3102.OT
Run remarks:           FILTER EFFICIENCY TEST
Impactor I.D.                    UWC1
                        UNIVERSITY OF WASHINGTON IMPACTOR 'C'

Water vapor           1.00% (From  'KEYBOARD)
Carbon dioxide       0.00%     Carbon monoxide   0.00%
Oxygen              21.00%     Nitrogen         79.00%

Sample train I.D.:               APT6HF
Gas meter volume                 72.848 cubic feet
Orifice DELTA P                   2.80 inches W.C.
Rotameter S.S. ball reading:     19.00
Stack pressure                   -1.00 inches W.C.
Barometric pressure              29.89 inches HG
Stack temperature               109 degrees F
Meter temperature                60 degrees F
Average Vacuum:                   8.00 inches HG
Impactor temperature             77 degrees F
  pactor DELTA P                  1.00 psi
Sample time                      32.00 minutes
Average velocity of gas      3,150.00 feet/minute
Nozzle diameter                   0.38 inches

     ***** RESULTS *****

Actual flow rate                 2.506 acfm
Satandard conditions             2.455 scfm
Percent isokinetic             109.91 %
Viscosity of gas stream          0.000182 g/cm-s

 STAGE       C.WEIGHT        C.CONC      C.FRACT         AERO. DIA.
                   mg       mg/DNm^3                         umA
 -----       --------        ------      -------         ----------
   1             1.20          0.55        1.000         11.48
   2             0.80          0.36        0.667          5.03
   3             0.80          0.36        0.667          1.94
   4             0.40          0.18        0.333          1.05
   5             0.20          0.09        0.167          0.64
  FILTER         0.10          0.05        0.083

Total mass concentration =      0.545 mg/DNm^3
```

```
              EFFICIENCY CALCULATIONS

     Project Number  79
     Run Number      3102

              * * * FINITE DIFFERENCE METHOD * * *

              Part. Dia.(umA)            Penetration (fraction)
                   0.60                              0.7917
                   0.70                              0.5473
                   0.80                              0.3975
                   0.90                              0.3036
                   1.00                              0.2392
                   2.00                              0.1399
                   4.00                              0.0133
                  10.00                              0.0001
```

DATA REDUCTION FOR ELECTRICAL AEROSOL SIZE ANALYZER

Test Number: 31-02

Test Date: 12-12-84

Reduction Date: 12-14-84

Filter Surface Velocity 5.5 **ft/min**

MEAN CUT DIAMETER (From Aerosol Size Analyzer) [μm]	PENETRATION (By Finite Difference Method) [Fraction]
0.0178	0.0010
0.0316	0.0040
0.0562	0.0032
0.100	0.0039
0.178	0.0021
0.316	0.0028

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project 79

DATA SHEET FOR MOLD TESTING

Test Number: 31-03

Test Date: 12-12-84

Mold Information:
Metal Type: TIN BRONZE

Metal Weight: 60 lb.

Sand Type: PETRO-BOND

Mold Dimensions (LxWxH) 16X16X22 in.

Ambient Conditions:
Temperature 72 °F

Relative Humidity: 72 %

Barametric Pressure 29.77 in. Hg.

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```
    *****     IMPACTOR DATA REDUCTION    *****

    *****   INPUT DATA    *****

Date of test:         12/12/84
Time of test:         1.30 PM
Test location:        SIMA-FOUNDRY
Project number:       79
Inlet/Outlet:        INLET
Run number:           3103 - FILE NAME: T79R3103.IT
Run remarks:          FILTER EFFICIENCY TEST
Impactor I.D.                       UWH1
                       UNIVERSITY OF WASHINGTON IMPACTOR 'H'

Water vapor           1.00% (From  'KEYBOARD)
Carbon dioxide       0.00%    Carbon monoxide    0.00%
Oxygen              21.00%    Nitrogen          79.00%

Sample train I.D.:                  APT10LG
Gas meter volume                    20.389 cubic feet
Orifice DELTA P                      0.30 inches W.C.
Rotameter S.S. ball reading:        19.00
Stack pressure                      +0.00 inches W.C.
Barometric pressure                 29.77 inches HG
Stack temperature                   75 degrees F
Meter temperature                   60 degrees F
Average Vacuum:                     10.00 inches HG
Impactor temperature                72 degrees F
  pactor DELTA P                     1.00 psi
Sample time                         32.00 minutes
Average velocity of gas          3,720.00 feet/minute
Nozzle diameter                      0.19 inches

     ***** RESULTS *****

Actual flow rate                     0.725 acfm
Satandard conditions                 0.716 scfm
Percent isokinetic                 100.59 %
Viscosity of gas stream              0.000181 g/cm-s

 STAGE        C.WEIGHT          C.CONC      C.FRACT         AERO. DIA.
                   mg         mg/DNm^3                          umA
 -----        --------          ------      -------        ----------
   1              2.50            3.90        1.000          21.28
   2              1.90            2.96        0.760           9.32
   3              1.50            2.34        0.600           3.61
   4              1.40            2.18        0.560           1.90
   5              0.80            1.25        0.320           1.13
   6              0.70            1.09        0.280           0.68
   7              0.50            0.78        0.200           0.40
  FILTER          0.40            0.62        0.160

Total mass concentration =      3.895 mg/DNm^3
```

```
*****     IMPACTOR DATA REDUCTION    *****

*****   INPUT DATA    *****

Date of test:       12/12/84
Time of test:       1.30 PM
Test location:      SIMA-FOUNDRY
Project number:     79
Inlet/Outlet:      OUTLET
Run number:         3103 - FILE NAME: T79R3103.OT
Run remarks:        FILTER EFFICIENCY TEST
Impactor I.D.                     UWG1
                     UNIVERSITY OF WASHINGTON IMPACTOR 'G'

Water vapor         1.00% (From  'KEYBOARD)
Carbon dioxide      0.00%     Carbon monoxide    0.00%
Oxygen             21.00%     Nitrogen          79.00%

Sample train I.D.:                  APT6HF
Gas meter volume                    64.907 cubic feet
Orifice DELTA P                      2.30 inches W.C.
Rotameter S.S. ball reading:        19.00
Stack pressure                      -1.00 inches W.C.
Barometric pressure                 29.77 inches HG
Stack temperature                   75 degrees F
Meter temperature                   60 degrees F
Average Vacuum:                     10.00 inches HG
Impactor temperature                72 degrees F
Impactor DELTA P                     1.00 psi
Sample time                         32.00 minutes
Average velocity of gas          3,720.00 feet/minute
Nozzle diameter                      0.38 inches

      ***** RESULTS *****

Actual flow rate                    2.186 acfm
Satandard conditions                2.153 scfm
Percent isokinetic                 77.05 %
Viscosity of gas stream             0.000181 g/cm-s

 STAGE       C.WEIGHT        C.CONC      C.FRACT          AERO. DIA.
                   mg      mg/DNm^3                            umA
 -----       --------       ------       -------          ----------
   1             1.70         0.88         1.000          12.25
   2             1.30         0.67         0.765           5.37
   3             0.90         0.47         0.529           2.07
   4             0.60         0.31         0.353           1.07
   5             0.40         0.21         0.235           0.63
  FILTER         0.30         0.16         0.176

Total mass concentration =      0.881 mg/DNm^3
```

```
          EFFICIENCY CALCULATIONS

     Project Number  79
     Run Number      3103

          * * * FINITE DIFFERENCE METHOD * * *

          Part. Dia.(umA)            Penetration (fraction)
               0.60                          0.1632
               0.70                          0.1542
               0.80                          0.1468
               0.90                          0.1781
               1.00                          0.2248
               2.00                          0.2283
               4.00                          0.3914
              10.00                          0.5094
```

DATA REDUCTION FOR ELECTRICAL AEROSOL SIZE ANALYZER

Test Number: 31-03

Test Date: 12-12-84

Reduction Date: 12-14-84

Filter Surface Velocity 6.5 ft/min

MEAN CUT DIAMETER (From Aerosol Size Analyzer) [µm]	PENETRATION (By Finite Difference Method) [Fraction]
0.0178	0.0052
0.0316	0.0038
0.0562	0.0040
0.100	0.0068
0.178	0.0032
0.316	0.0015

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project 79